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IN CONFIDENCE **SCOS93/2**
NATURAL ENVIRONMENT RESEARCH COUNCIL **ANNEX I**

ADVICE ON THE STATUS OF BRITISH GREY SEAL POPULATIONS: 1993

Every year the Sea Mammal Research Unit (SMRU) conducts surveys of the major grey seal breeding sites in Britain in order to estimate the number of pups born there. During 1992 aerial surveys were flown of all the major sites in the Hebrides and Orkney, and of the Isle of May. Ground counts of the numbers of pups born at the Farne Islands were carried out by staff from the National Trust; similar counts were carried out by members of the Lincolnshire Trust for Nature Conservation at Donna Nook on the Humber estuary, by members of the Dyfed Wildlife Trust in Wales, and by staff of Scottish Natural Heritage on South Ronaldsay, Orkney. The coasts of Dumfries and Galloway, including much of the Solway Firth, were surveyed for common seals in August 1992. No grey seals were seen during this survey.

Annex I (Hiby et al., *in prep.*) presents estimates of pup production based on surveys of grey seal breeding sites carried out since the 1950s. It also describes the methods used to calculate these estimates and the size of the total seal population associated with a group of sites. It includes maps of the British and world distribution of the grey seal, and of the location of sites on Scotland where grey seals have been observed in summer during surveys for common seals.

The method described in Hiby *et al.* provides an estimate of the total seal population associated with all the breeding sites which are surveyed annually. For illustrative purposes the components of this population which are associated with each of the major breeding areas have been calculated. However, it should be recognized that the distribution of seals outside the breeding seasons is unlikely to be the same as the distribution of the breeding sites. Estimates of pup production and population size for the main colonies surveyed in 1992, which account for more than 85% of all pups born each year, are:

Location	Pup production	Change from 1991	Total population (to nearest 100)
Inner Hebrides	2723	+11%	9600
Outer Hebrides	11458	+11%	40500
Orkney	9116	+11%	32200
Isle of May	1169	-4%	4100
Farne Islands	985	+6%	3500

The pup production figures in this table have been calculated using the same procedures as in previous years. However, the 1992 survey results suggest that there may have been a change in the distribution of births through the pupping season which will require some modification to the surveying strategy and estimation procedure. This is discussed in more detail in Section 5 of Annex I.

Ninety-five percent confidence limits on the sum of the pup production estimates are within 10% of the point estimate. It is also possible to calculate 95% confidence limits for the estimate of the female component of the population; these are within 35% below and 73% above the point estimates. The size of the male component of this population has been derived in a different way, as a result it is not possible to calculate formal confidence limits for the estimate of total population size. However, if it was possible they would be at least as large as those for the female component.

The other British breeding areas are surveyed less frequently and intensively. Estimates of pup production have been calculated for these, but confidence limits cannot be calculated. The total population associated with these remaining areas has been calculated using the ratio of total population to pup production for the main areas. The resulting figures are:

Location	Date of last survey	Pup production	Total population (to nearest 100)
Mainland Scotland	1992	837	3000
Shetland	1977	1000	3500
Humber estuary	1992	200	700
Southwest Britain	1973/92	1550	5500

Taken together, these figures provide an estimate of 102,700 for the size of the British grey seal population at the start of the 1992 pupping season. This is 40-45% of the world population of the species. 93,000 seals are associated with breeding sites in Scotland and 9,700 with breeding sites in England and Wales. The equivalent estimates for 1991 are 86,400 for Scottish sites and 7,100 for those in England and Wales. The increase in population size between the two years was 11%. The increase in numbers for Wales is a result of the new surveys conducted by the Dyfed Wildlife Trust.

THE STATUS OF THE BRITISH GREY SEAL POPULATIONS

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1. BASIC BIOLOGY

The grey seal is Britain's largest land mammal. Males may weigh in excess of 300kg, but most adults are 1.6-2.3m in length and weigh 120-250kg. Pups weigh 13-14kg at birth and grow to around 45kg in the first three weeks of life. Females may live up to 45 years.

The species breeds colonially at a limited number of remote coastal sites between September and December. Most of these sites are on islands off the north and west coast of Scotland, but there are now a number of colonies at mainland sites in Scotland and England (Figure 1). At most colonies females remain ashore with their pups throughout the three-week lactation period. At the end of this period, adult females are mated by males which have maintained a position within the colony. Females return to the sea after mating, but pups may remain ashore for several weeks after they have been weaned. Pups are born with a silky white coat, which shows up clearly in coloured aerial photographs but which is moulted after 2-3 weeks. At each colony pups are born over a 4-6 week period, so that there is no one time when all the pups born at that colony are actually present. The timing of births varies considerably from colony to colony, but year to year variation within a colony is limited to only a few days.

Adults and pups appear to disperse widely after the breeding season and relatively small numbers are observed around the breeding colonies and at other sites which are used for hauling-out. However, during the moult, which occurs from January to March for males and from March to May for females, dense aggregations can be observed at favoured sites.

2. WORLD POPULATION

The grey seal is confined to the North Atlantic, population size is usually assessed by counting the number of pups born each year, either directly or from aerial photographs. There are discrete populations in Canada and the northern USA, the north-east Atlantic, and the Baltic Sea (Figure 2). The population in the north-west Atlantic is increasing, the Baltic population has decreased sharply but now appears to be stable. In the northeast Atlantic there are sizeable populations in Iceland, the Faroe Islands, Norway and the UK. Approximately half of the world's population breeds around the coast of Britain. Very small colonies (producing 1-5 pups per year) exist in France, the Netherlands, Germany and the Kattegat.

3. ESTIMATING PUP PRODUCTION AT BRITISH SITES

This section provides a brief outline of the methods used to estimate pup production of grey seals at each of their major breeding sites, and presents the best estimates currently available. **The method used to estimate pup production in 1992 was the same as for each year since 1984. However, section 5 outlines some apparent shortcomings of that method revealed by the data collected in 1992 and suggests some modifications that may be required in future years.**

3.1 Surveys of Pupping Sites

Methods of data collection and analysis are more fully described in Hiby, Thompson and Ward (1987) and Ward, Thompson and Hiby (1987). Very briefly, all major breeding sites in the Inner Hebrides, Outer Hebrides and Orkney island groups are photographed three or four times at an interval of about 10 days, from late September to mid-November each year. Photographs are taken on colour transparency film from the NERC aircraft using a 5 inch format camera on a vibration-damped and motion-compensated mount. The frames are taken in overlapping series and aligned using common features visible on adjacent frames to provide a complete coverage of the areas used for breeding. A census of the white-coated and moulted pups present on a site on each of the days it was photographed is then obtained by inspecting the frames on a micro-fiche viewer. Pups which are obviously dead, judging by their appearance on the photographs, are recorded separately. However, this provides only a lower bound on the number of dead pups and the subsequent analysis is based on the total pup counts. This assumes that pups which die remain visible to the aerial survey for a period which is equal, on average, to the age at which surviving pups leave the site (or, in the case of analyses based on white-coated pups only, to the age at which surviving pups moult).

3.2 Statistical Methods for Estimation of Pup Production

The number of pups born at each site is estimated using a computer model of the growth and decline of the number of pups present on a site during a breeding season. The model has been applied to all data collected since 1983. Prior to 1983, production at each site was estimated by multiplying the maximum aerial survey count by a calibration factor derived from selected ground counts of islands in the Outer Hebrides and Orkneys.

Production can be observed directly from an intensive series of ground counts by dye-marking pups during each count and summing the number of unmarked pups counted over the series. This production estimate can then be compared to the maximum total count of live pups to derive a calibration factor. However, to apply this factor to aerial survey counts it is necessary to assume that only live pups are counted from the photographs, and that the maximum number of live pups present during the season is unaffected by the ground counts themselves. Results of the current analyses indicate that one or both of these assumptions do not hold. The calibration factor method is also unsound as a statistical procedure given that fact that the timing of the breeding season is not known before the flights are conducted. If the flights are widely spaced in time there may be no flights conducted at or near the time that the maximum number of pups are present on a site, leading to a downward bias in the peak count. On the other hand, a number of flights may be conducted during a period when a constant maximum number of pups is present on the site. In that case, any random error present in the counts will lead to a positive bias in the maximum count obtained from the photographs as an estimate of the maximum number of pups present.

3.2.1 Variance of Pup Production Estimates

In the model, date of birth is assumed to be normally distributed with a standard deviation of 10 days. The predicted number of pups present on the day of each flight is calculated assuming that the interval between birth and the time at which the pup disappears (when the corpse becomes obliterated or, in the case of surviving pups, the pup goes to sea) is also normally distributed with a mean of 31.5 days and a standard deviation of 7 days - those parameter values are based on observation of known-age pups on the Isle of May in 1985, 1986 and 1987 (Wyile, 1988).

The covariance matrix for the joint distribution of the number of pups present on the flight days is calculated assuming that the birth day and day of disappearance are independent for different pups, and that the number of pups is counted without any error. **However, there is almost certainly some dependence between different pups in the actual days of birth and disappearance (for example, we can imagine pups leaving in small groups so that the effective sample size for parameter estimation is less than the number of individual pups present). The matrix is therefore scaled up to reflect this variation and any further lack of fit in the model. These adjustments have little effect on the production estimate itself but considerable effect on its estimated coefficient of variation (CV).**

3.2.2 Estimating Pup Production at Sites with Small Numbers of Counts

In the current version of the model the likelihood is maximised with respect to the mean date of birth, the covariance matrix scaling factor, and the production. This thus requires a minimum of three counts during the season. In those cases where only two counts are available the scaling factor, and hence the CV, cannot be estimated; when there is only one count (as occurred for some sites in 1985) the production can only be estimated given a mean birth date. In the latter cases the mean date has been interpolated from the estimated mean birth dates for site/years with at least two counts. Figure 3 shows the mean of those estimates by year and island group. There is little change in the values from year to year but a gradual drift over time. For sites in the same island group there is a degree of coherence between changes in the timing of the breeding season. Figure 3 suggests that this may also apply to the island groups. For the moment we have chosen to model mean birth date as a cubic function of year, with quadratic and cubic terms constrained to be the same for islands in the same group. Constant and linear terms are specific to site because there are large mean differences in birth date for sites in the same group and some sites, particularly those experiencing a steady increase or decline in pup production, have shown a trend in birth date over the period of the surveys. Although satisfactory for interpolation over a series of short duration the polynomial fit is not suitable for providing predictions of birth dates for the following year (required for flight planning) and is not appropriate for longer series. Statistical forecasting models will be applied to this data in future years.

3.2.3 Analysis of Surveys Conducted before 1983

The data for years before 1983 were not available in a form suitable for the model, so the results presented for those years are still based on a calibration factor. The value was based on the model results for 1984-92; it was 1.210 for the Outer Hebrides and 1.231 for the Orkneys (regular counts of the Inner Hebrides were not obtained before 1984). With the parameters as set in the model the ratio between production and maximum pups present is 1.19 - any increase in this figure results from displacement of the date at which the maximum count was obtained from the date at which the model calculates the maximum number of pups to have been present.

3.3 Estimates of Pup Production

Tables 1, 2 and 3 give the pup production estimates produced by this procedure for each site in the Inner Hebrides, Outer Hebrides and Orkneys, totals for each group and, in the case of the Outer Hebrides, a sub-total for the Monach Isles which have been colonised during the period covered by the data series and shown a rapid growth of pup production recently. There are some interpolated production values in earlier years included to avoid breaks in the time series for group totals. These are for Haskier in 1966-68 and Shillay in the Monachs for 1972. The 1978 estimate for North Rona is based on ground counts. The 1977 total for the Outer Hebrides, when an adult and pup cull took place, is taken from data records held at SMRU. The basis for the estimate is unclear - aerial survey counts were not obtained for this group in 1977.

3.3.1 Colonies with Incomplete Time Series

A general problem in inferring a trajectory of total pup production for a group of colonies from these data is that not all sites have been surveyed throughout the period because initially they were not used by seals or used by only a few seals. Survey of a site may be initiated when it is first noticed that the site is used by a significant number of seals, resulting in an overestimate of the rate of increase of total production for the group. The effect should be fairly small, however, particularly in recent years. The series for Deasker shows the opposite effect: no pups have been observed there since 1983. It is possible that counts made before 1983 included a number of yearling seals which are present at this site during the breeding season.

Sites on South Ronaldsay in the Orkneys are not suitable for aerial photography, hence the lack of estimates following 1983, since when all Orkneys and Hebrides estimates have been based on aerial survey. However, Scottish Natural Heritage began to make systematic counts of the South Ronaldsay sites during the 1991 pupping season.

3.3.2 Estimation of Coefficient of Variance for Total Pup Production

For any year/site with three or more counts the model can provide an estimate of the error on the production estimate, as a CV. However, with the model set to use a fixed standard deviation of 10 days for the birth curve, the CV generated is unrealistic. This is because it fails to incorporate uncertainty about the true duration of the pupping season for that site in that year.

The following procedure was adopted to overcome this difficulty. In certain years, sufficient flights were conducted over some sites to estimate the birth curve standard deviation and provide a CV for the resulting production estimate (the value of 10 days was based on these results). This applied to 21 of the 35 sites in 1987 and 29 sites in 1988. The average CV over all these site/years, weighted by the production estimates, was 0.09, suggesting a CV of around 10% as a rough guide to the accuracy of a production estimate by this method for a given site in a given year. Summing estimates to provide totals by year, and assuming errors on estimates for different sites are independent, gave CV's of 0.033 in 1987 and 0.017 in 1988 on the total production estimates for those years. This would indicate a CV of 3% as a rough guide to the accuracy of production totals for successive years. However, given that the average number of counts per site were lower in other years, and that variation in weather conditions generates dependence between the errors for sites surveyed on the same flight, it would be safer to increase this figure to, say, 5%.

3.3.3 Sites not Surveyed from the Air

Table 4 gives available estimates for other sites, not included in the aerial survey programme (except that the Isle of May was photographed in 1988, 1989, 1991 and 1992, and Loch Eriboll was photographed in 1992). The number of pups born at the Farne Islands and Donna Nook are counted each year by the National Trust and the Lincolnshire Trust for Nature Conservation respectively. Some sites in Shetland, mainland Scotland, Wales and Cornwall are located on inaccessible beaches or in caves under steep cliffs. These cannot be surveyed effectively from fixed-wing aircraft and can only be visited during calm weather or by helicopter. Most of them are small and they are surveyed at irregular intervals whenever resources are available. The Dyfed Wildlife Trust, with financial support from the Countryside Council for Wales, has begun a survey programme which will run until 1996 and will provide a new estimate for pup production in Wales. A provisional estimate based on data collected in 1992 is incorporated in this report.

3.4 Pup Production Trends

Figure 4 plots the estimated trajectory of pup production totals for islands in the Orkney group; it suggests a fairly continuous increase in the Orkneys breeding population from the mid 1960s to the present. There is an indication of some discrepancy in the trajectories before and after 1983. This may be partly due to the use of the production:peak-count ratio from the recent analyses to scale up the peak counts for the pre-1983 surveys. The flights in the recent surveys have been more widely spaced in time in order to estimate the spread of the birth curve, so that on average the production:peak count ratio now may be slightly higher than before 1983. In addition, the use of monochrome aerial photographs before 1983 may have led to over-counting under certain conditions.

Figure 5 plots the pup production trajectory for the Outer Hebrides, and the sub-totals for the Monach Isles and the rest of the group. It shows that the increase in the breeding population has occurred primarily at the Monach Isles. The plot also illustrates the effect of the breeding season cull carried out in 1977, which depressed the pup production in 1978 by more than would be expected as a result of the loss of the culled seals from the local population.

In Figure 6 the trajectories from the Orkneys and Outer Hebrides have been added to those from the Farnes and Isle of May to illustrate the changes in pup production for the majority of sites in Scotland and Northumberland. The Inner Hebrides estimates are excluded because the estimates for the group as a whole are not available before 1984; estimates for Loch Eriboll, Helmsdale and the Shetlands are also excluded.

Figure 7 plots the estimated pup production trajectories for the Orkneys, Outer Hebrides, Farnes plus Isle of May, *and* the Inner Hebrides, from 1984 to 1992. The effect of the 1988 phocid distemper virus epidemic is clearly visible in the line showing the total for all groups, and also in the Orkney and Farnes plus Isle of May trajectories, but not for the Hebrides. The fact that the total trajectory has remained depressed since 1988 suggests that the effect of the virus was to kill adult seals rather than to cause a temporary drop in fecundity.

4. ESTIMATING THE NUMBER OF SEALS ASSOCIATED WITH BRITISH BREEDING SITES

We believe that the trajectories of pup production estimates provide the most sensitive available indicator of any response by the breeding populations to factors such as disease, disturbance, pollution, food or space limitation, and also provide the most reliable indication of their geographical distributions. There is, however, a requirement to estimate, each year, the surviving number of seals of all ages which were born at any British site, which is motivated by interest in potential interactions with commercial fisheries. Before describing the model used to estimate this number, we consider the parameters which determine the ratio between pup production and the size of the "all-age population", and the possible range of values for this ratio.

4.1 Ratio of Female Population Size to Pup Production

It is sufficient for this purpose to use a simplified population model with "knife-edge" recruitment of female seals to the breeding population at age k years, i.e. females may have their first pup on their k^{th} birthday. Suppose the proportion of pups which survive from birth to age 1 is S_j and annual survival for seals beyond age 1 is S. Let the population have a stable age-structure and an annual rate of increase of λ.

Then the ratio of the number of females aged 1 and over at the time of the breeding season to the production of female and male pups during that season equals $(\frac{\lambda}{S})^{(k-1)} \times \frac{1}{F}$, where F represents fecundity (ie the number of pups of either sex produced per year by each adult female). This follows from the balance equation linking production to the population vector. For example, with S and F set to 0.94, k set to 5 years and an annual increase of 1.07 in the size of the population, the female population at the time of the breeding season is about twice as big as the pup production.

The point of this derivation is that it allows the minimum size of the female population associated with an observed production trajectory to be calculated. As S and F cannot exceed one, and assuming a female cannot have a pup before her 5th birthday, the minimum population size equals λ^4 times the pup production, i.e. about 1.3 times for $\lambda = 1.07$.

To calculate the *maximum* female-population:total-pup-production ratio the formula can be recast as $\frac{\frac{S_j}{\lambda}}{2(1-\frac{S}{\lambda})}$ which is maximised by letting S tend to 1 and S_j tend to 0.8 (to represent survival to age 1 if no pups die after leaving the breeding sites). With λ set to 1.07 again the maximum ratio equals 5.7.

The minimum and maximum ratios correspond to S_j and F, respectively, tending to zero. These calculations are useful in identifying the degree of uncertainty associated with estimates of total population size in the absence of reliable information on either survival rates or fecundity and age at first breeding. They set feasible bounds for the size of the population but they should not be taken as estimates of the maximum of minimum number of British seals. The limits can also be useful for comparison with confidence limits generated by the computer model used to estimate total population size from observed production trajectories. It should be noted that a further degree of uncertainty is involved in extrapolating from female to female-plus-male population size, because males may suffer different rates of mortality, and very little information is available on this.

4.2 Technique used to Estimate Total Population Size

The statistical model used to estimate all-age population sizes is described in Appendix 1. The details of the method are complex but in outline the method is as follows:

Mean fecundity rate (pups born per year per female following the age of first breeding) is determined in the model using data from a cull of females at the Farnes in 1981. The values used in the model for the proportion of females having their first pup at each age are from Harwood and Prime(1978) - recruitment occurs over a 3-year age interval. Using these parameter estimates the number of "mature" females in an isolated population associated with a given group of breeding sites can be estimated, for a given year, from the pup production at those sites in that year. This leaves immature females and males to be estimated. The number of females in each pre-breeding age class in the given year is available from an age-structured population model, given a series of pup production estimates leading up to that year and estimates of age-specific survival rates. Survival was assumed to be the same for all age classes following the first year, with a lower survival for the first year of life, as in the model described at the beginning of this section. These two survival rates are estimated by comparing model-predicted and observed pup productions. Estimates of both parameters are available if the number of pups known to be recruited to the population each year varies as a result of variations in pup production and pup culls. The method is formulated as a maximum likelihood estimation model with the observed pup productions and the number of pregnant females in the Farnes cull as the random variables. The error structure assumes fecundity rate varies independently from year to year and ignores any error in estimation of pup production or fluctuation in survival rate. Subject to these assumptions, confidence limits on the population size estimate for a given year are available, using the likelihood ratio method.

4.3 Construction of Time Series for Use in Population Estimation

4.3.1 Farne Islands Population

By far the longest and most reliable series of pup production estimates available is that for the Farne Islands. The computer model was applied from 1956 to 1971 to give maximum likelihood estimates of 0.94 for F and 0.95 and 0.51 for S and S_j respectively. Ninety-five percent confidence limits on the population estimates are 35% below and 45% above the maximum likelihood estimates, i.e. well within the upper limit calculated at the beginning of this section and roughly equal to the lower limit.

4.3.2 Dealing with the Effects of Culls

Comparison of predicted and observed pup productions is appropriate only if the mature females estimated to be in the population can be assumed to breed only at the included sites, and those sites are not used by other females. Furthermore no change in fecundity rate, other than independent random fluctuations from year to year, are allowed for in the model. Because of possible changes in fecundity and migrations of the breeding populations following adult culls in 1972 and 1975 in the Farnes, the production estimates following 1971 cannot be used for parameter estimation.

One way to proceed is to assume that mortality rates remain the same as those estimated for the pre-cull years and allow the model simply to accumulate the observed productions into the estimated total population, subtracting any animals killed in culls and those eliminated by natural mortality. The population estimates shown in Figure 8 for 1972-92 were calculated on this basis. They include the production estimates obtained for the Isle of May since 1979; thus they refer to the animals **born** at the Farnes or the Isle of May: some of these animals may now be breeding elsewhere. Such estimates are of little value, because even if the assumption of constant mortality holds, the estimates refer to a population for which not even the breeding component is uniquely associated with a defined area. The same problem applies to the Outer Hebrides where a cull in the 1977 breeding season may have led to migrations affecting both the number and age structure of seals in that area. An obvious solution is to add the estimated production trajectories from different areas and derive a population estimate for the entire area which is unaffected by migrations within it. The only difficulty is that gaps in the production trajectories for each area lead to a very fragmented trajectory of totals. However, the surveys conducted each year since 1983 have been very comprehensive and the production totals, illustrated in Figure 9, refer to all sites in Scotland and Northumberland excluding Eriboll, Helmsdale and the Shetlands. These pup production values are listed in Table 5.

4.4 Final Estimates of Total Population Size

Running the computer model on the series of production totals from all sites in Scotland and Northumberland, excluding Eriboll, Helmsdale and Shetland, gave the female population estimates listed in the Table 5 and plotted in Figure 9. It was not possible to estimate both first year survival, S_j and subsequent survival, S. S was fixed at 0.95, the value estimated from the Farnes data from 1956 to 1971. The resulting estimate for S_j was 0.50.

The confidence limits calculated for these estimates of female population size are only slightly wider than those for the pre-1972 Farnes population estimates, which were based on a much longer data series. This is because S was given a fixed value. One way to make the confidence limits incorporate uncertainty concerning the value of this parameter is to recalculate them with S set against its biologically determined constraints. Reducing S increases the population estimate and the estimate of S_j. It is reasonable to suppose that survival from birth to age 1 should not exceed annual survival beyond age 1. Reducing S to 0.93 increases the estimate of S_j to the same value (given an 80% survival of pups on the breeding sites) and increases the upper limit to 72% above the estimate. The lower limit of 35% below the estimate is given by the argument at the beginning of this section.

In summary, the second column of Table 5 lists, for each year from 1984 to 1992, point estimates for the number of female seals of age 1 or over at the time of the breeding season, which are associated with all the major breeding sites in Scotland and Northumberland, with the exception of Eriboll, Helmsdale and the Shetlands. The estimation model assumes that all these seals were born at one or other of the sites, and use only these sites for breeding; furthermore that these sites are not used for breeding by seals born in other areas. The possible range of error on these estimates, derived as a hybrid of 95% confidence limits and the result of allowing annual survival to vary across its feasible range, is from 35% below to 72% above the point estimates listed.

The third column in Table 5 lists point estimates for the number of female *and* male seals. The estimates assume equal numbers of males and females up to the age 5 and a female to male ratio of 1.6 for older seals. These figures are based on the assumption that the two sexes have similar survival rates up to the age of sexual maturity and that adult males have an annual survival of 0.8 thereafter. The latter figure is derived from the age structures of males more than 10 years old killed in management culls at the Farne Islands in 1972 and 1975 (Harwood and Prime, 1978). It is not possible to calculate formal confidence limits for the estimate of total population size; if it were, they would certainly be larger than those for the female component of the population. The sensitivity of the estimate to the assumption about adult male survival can be gauged from the fact that the estimates in the third column of Table 3 would be increased by about 10% if adult males and females had identical survival rates.

5. LACK OF FIT TO THE PUP PRODUCTION MODEL

Figure 11a shows the total pup counts for Ceann Iar in the Monachs and the model fit in 1988. Six survey flights, rather than the usual three or four, were conducted in 1988 to allow the spread of the birth curve to be estimated. The results were consistent with the hypothesis that pupping date was normally distributed with a standard deviation (SD) of 10 days. In other island/year data sets for which an extensive set of counts exists the same conclusions held generally, although there were minor exceptions. For example, the counts for Causamul in the Outer Hebrides have often been poorly fitted by the model, possibly due to immigration from neighbouring sites in the Monach Isles. However, only around 100 pups are produced at this site, so that the effect of any error in the pup production estimate on the estimate for Britain as a whole is negligible.

In 1992, however, the pup production model based on a normal birth curve with an SD of 10 days did not fit well to most data sets. For example, Figure 11b shows the results for Ceann Iar in 1992. The fits are generally improved by allowing a wider birth curve. However, since 1988 the count series have not been extensive enough to allow reliable estimation of the birth curve SD. If birth curve SD is included as a free parameter, the estimated pup production for Ceann Iar increases by 30% from 1991 to 1992 with a 28% increase in the Outer Hebrides as a whole.

Although such an increase is just conceivable, a year to year comparison of the count data itself (Figure 12) does not support it. Rather, it suggests that the apparent increase is an artifact resulting from a change in the average date the survey flights were conducted. The 1992 flights were conducted later; they reveal more of the descending part of the pups-ashore curve and less of the ascending part. An increase in the estimate of birth curve SD may thus be the result of fitting a symmetrical model to different parts of an asymmetric data curve, rather than a true increase in the width of that curve. The most likely source of such asymmetry would be recruitment to the breeding population of young females whose average pupping date is later than the existing mean pupping date.

To check this possibility we extended the maximum likelihood model for estimating pup production to incorporate both moulted and white-coated pup counts rather than just total counts of pups, and used measurements of the distribution of age-at-moult from the Isle of May in the model. This doubles the number of available data points from each survey, and might have provided the means to investigate asymmetric models for the distribution of pupping date. Unfortunately it proved difficult to classify pups on the photographs consistently into the moulted and white-coated classes, thus nullifying the potential gain in information. Some ground-truth data is available to estimate misclassification probabilities but not sufficient, given the range of lighting conditions affecting the photographs. The problem is particularly difficult given that the counts are made by researchers who are aware of the timing of the counts and hence also the expected proportion of moulted to white-coated pups on the ground.

We concluded that it was not possible to address this problem adequately with the data now available and decided to base the production estimates on the same model for birth date as used in previous years: ie normally distributed with a SD of 10 days. However, the model for number of pups ashore has been refined to give a certain degree of asymmetry in the pups-ashore curve. Data from the Isle of May suggest that the expected age at which pups leave the breeding beach is lower for pups born later in the season. Re-analysis of that data gave an estimate of 0.39 days decrease in expected age at leaving per day increase in birth date. This adjustment was included in the production estimation model this year, plus an assumed 5% undercount of pups ashore due to early death and disappearance from view of a proportion of the pups ashore.

We are considering three possible changes to the production monitoring process to address these problems. The first is to increase the number and spread of flights to provide data similar to that obtained in 1988. This would involve at least 50% more effort in terms of flights and counts. The second is to improve the classification into moulted and white-coated pups by obtaining more ground-truth data. It might then be advantageous to have photographs counted independently by workers who were unaware of the timing of the flights to generate a simpler structure for the misclassification errors. The third is to identify and count pups which are suckling in the aerial photographs and have the production model predict the values of such counts rather than total pup counts. The predictions would be based on observation of the proportion of time spent suckling by pups of known age. Some data on this already exist and further data could be obtained relatively easily. Another possibility, which should be cost-effective in the long term, is to automate the counting process, either using colour slides as the image capture medium, as at present, or a combination of thermal and colour visual line scan devices to generate images and counts in "real time". Development of such systems is, however, beyond the scope of the available budget at present.

6. DISTRIBUTION

Some information on the distribution of grey seals outside the breeding season is available from the aerial surveys for common seals conducted in August 1988-92 (see Figure 12 and Duck *et al.*, in prep.). The area covered includes the entire north and west coasts of Scotland from Duncansby Head in Caithness to Silloth in Cumbria, including Shetland, Orkney and the Outer Hebrides. Sections of the east coast of Scotland have not been surveyed: the Helmsdale coast from Duncansby Head to Golspie, the Buchan and Aberdeen coast from Findhorn to Carnoustie, and the Fife and Lothian coast south of St. Andrews. Outlying islands (St. Kilda, North Rona, the Flannans, Sule Skerry, Sula Sgeir, Sule Stack and Fair Isle) have not been surveyed due to CAA restrictions on the use of the survey helicopter over open water. The common seal surveys are clearly contributing to the build up a more complete picture of the distribution and use of grey seal haul-out sites during the summer.

7. EXPLOITATION AND DELIBERATE KILLING

Licences to take grey seals within the close season (September-December) may be granted by the Secretaries of State for Scotland and the Home Department for five reasons: scientific or education purposes; prevention of damage to fisheries; reduction of population surplus for management; use of a population surplus as a resource; and protection of flora and fauna. Historically most licences were issued to take pups to reduce a population surplus. However, the dramatic decline in demand for seal products in recent years has meant that licences are now only requested for prevention of damage to fisheries and protection of flora and fauna. Table 6 documents the number of grey seals taken under licence since 1962.

In 1992, 10 pups were killed by the National Trust at the Farne Islands under a licence issued by the Home Office; 423 grey seals were handled in England and Scotland under licences issued for scientific purposes, 4 of these died. A number of seals are shot legitimately each year by fishermen and owners of marine fish farms. No reliable figures are available for the number of grey seals killed in this way, but figures provided to SOAFD by the Salmon Net Association and the Scottish Salmon Growers Association indicate that at least 234 grey seals were shot in 1989 and 1990.

7. REFERENCES

HARWOOD, J., and PRIME, J.H. (1978) Some factors affecting the size of British grey seal populations. J. appl. Ecol. 15: 401-411.

HIBY, A.R., THOMPSON, D., and WARD, A.J. (1987) Improved census by aerial photography - an inexpensive system based on non-specialist equipment. Wildl. Soc. Bull. 15: 438-443.

WARD, A.J., THOMPSON, D., and HIBY, A.R. (1987) Census techniques for grey seal populations. *In* Harris, S.J. (*Editor*) Symposia of the Zoological Society of London, 58: Mammalian Population Studies. Oxford University Press, Oxford

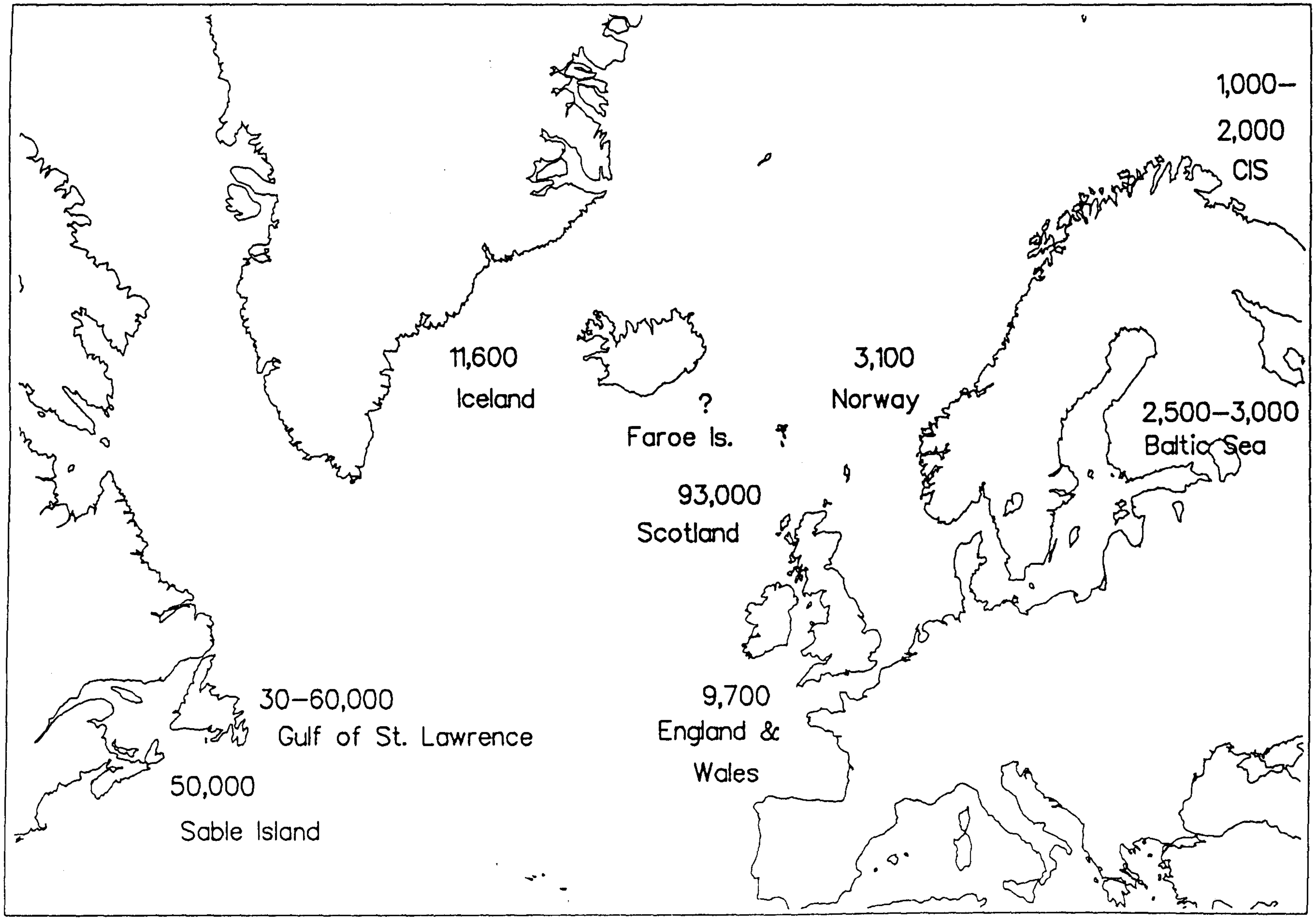
WYILE, G. 1988. Assessment of grey seals production from counts of pups. PhD Thesis. University of Cambridge.

8. FIGURE CAPTIONS

Figure 1	Distribution of main grey seal breeding sites in Britain.
Figure 2	Distribution and size of grey seal populations in the North Atlantic.
Figure 3	Variation from year to year in mean date of pupping at grey seal colonies in different island groups around Britain. 0 = 1 October.
Figure 4	Variation in numbers of pups born at grey seal colonies in Orkney 1960-1992.
Figure 5	Variation in numbers of pups born at grey seal colonies in the Outer Hebrides 1960-1992 ("pro.OHeb"). Pup production at the Monach Isles (+ "pro.Mon"), and at the other colonies in the Outer Hebrides ("pro.OH-M") are also shown.
Figure 6	Changes in combined pup production for major grey seal colonies in Scotland (Outer Hebrides, Orkney, Isle of May) and Northumberland (Farne Islands) over the period 1960-1992.
Figure 7	Changes in pup production at grey seal colonies in the major island groups around Britain over the period 1984-1992. "pro.OHeb"=pup production in the Outer Hebrides, "pro.Ork"=Orkney, "pro.IH"=Inner Hebrides, "pro.F+IOM"=Farne Islands and Isle of May. "pro.Tot"=all colonies combined.
Figure 8	Pup production ("production") and estimated total population size ("pop.F+IOM") for the grey seal colonies at the Farne Islands and the Isle of May over the period 1956-1992.
Figure 9	Pup production and estimated total population size ("pop.Tot") for all grey seal colonies in Scotland (excluding Eriboll, Helmsdale and Shetland) and Northumberland over the period 1984-1992.
Figure 10	Distribution of numbers of greys seal hauled out in Scotland as revealed by surveys for common seals conducted in the summers of 1988-1992.
Figure 11a	Observed numbers of pups ashore and model fit for Ceann Iar in 1988.
Figure 11b	Observed numbers of pups ashore and model fit for Ceann Iar in 1992.
Figure 12	Observed numbers of pups ashore for Ceann Iar in 1990-1992.

Figure 1 MAIN GREY SEAL BREEDING SITES

Figure 2



Distribution and Abundance of Grey Seals in the North Atlantic

Figure 3 Mean Birth Dates in Main Island Groups

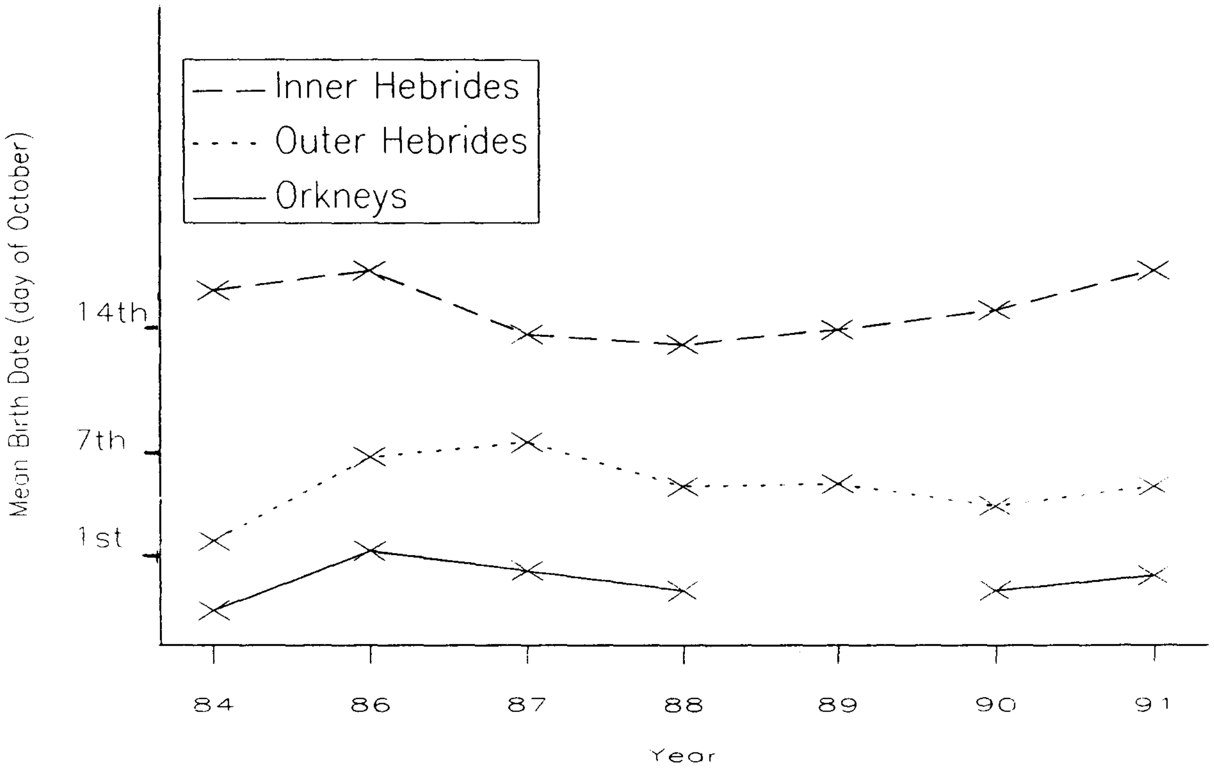
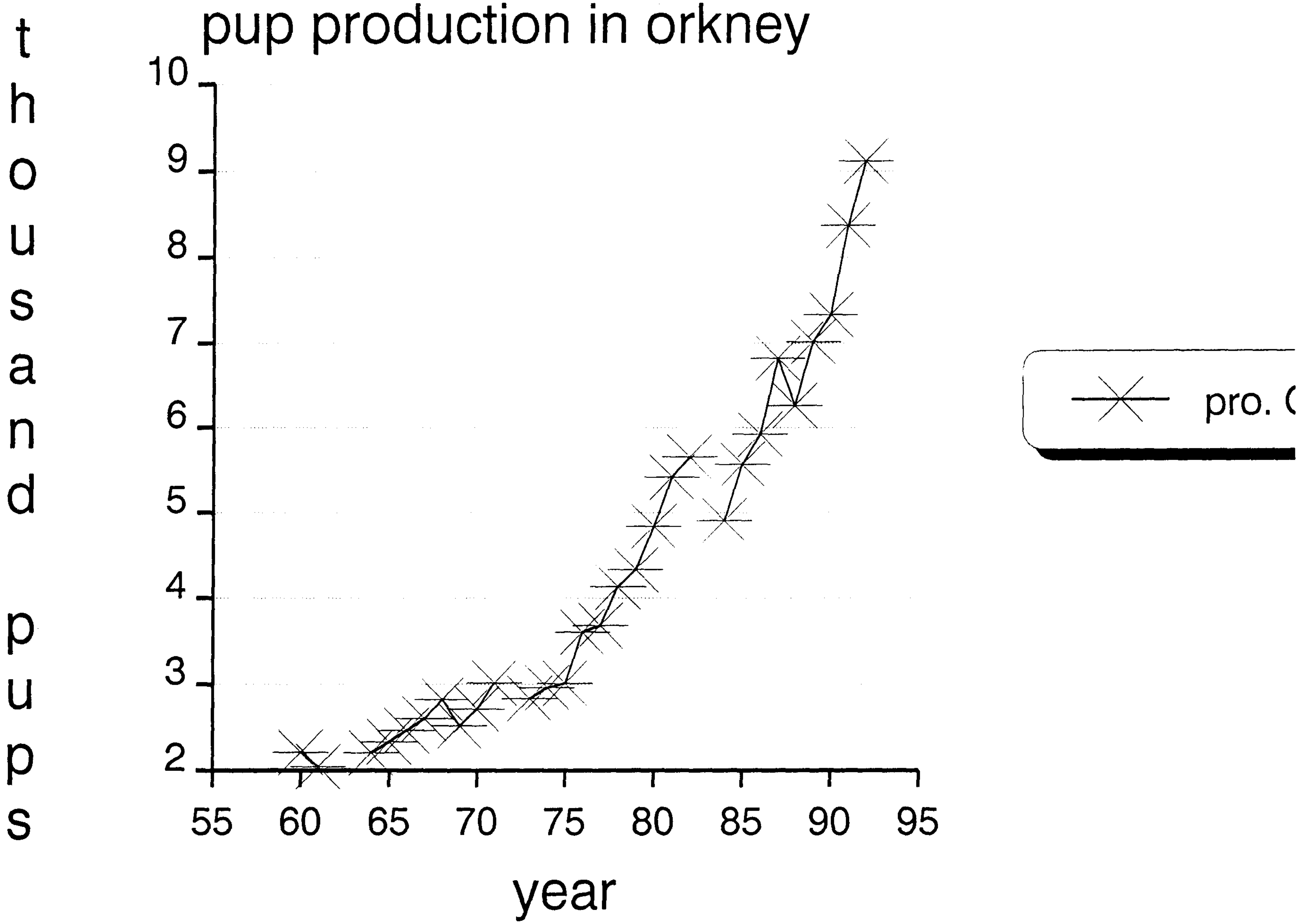


FIGURE 4



pup production in orkney

FIGURE 5

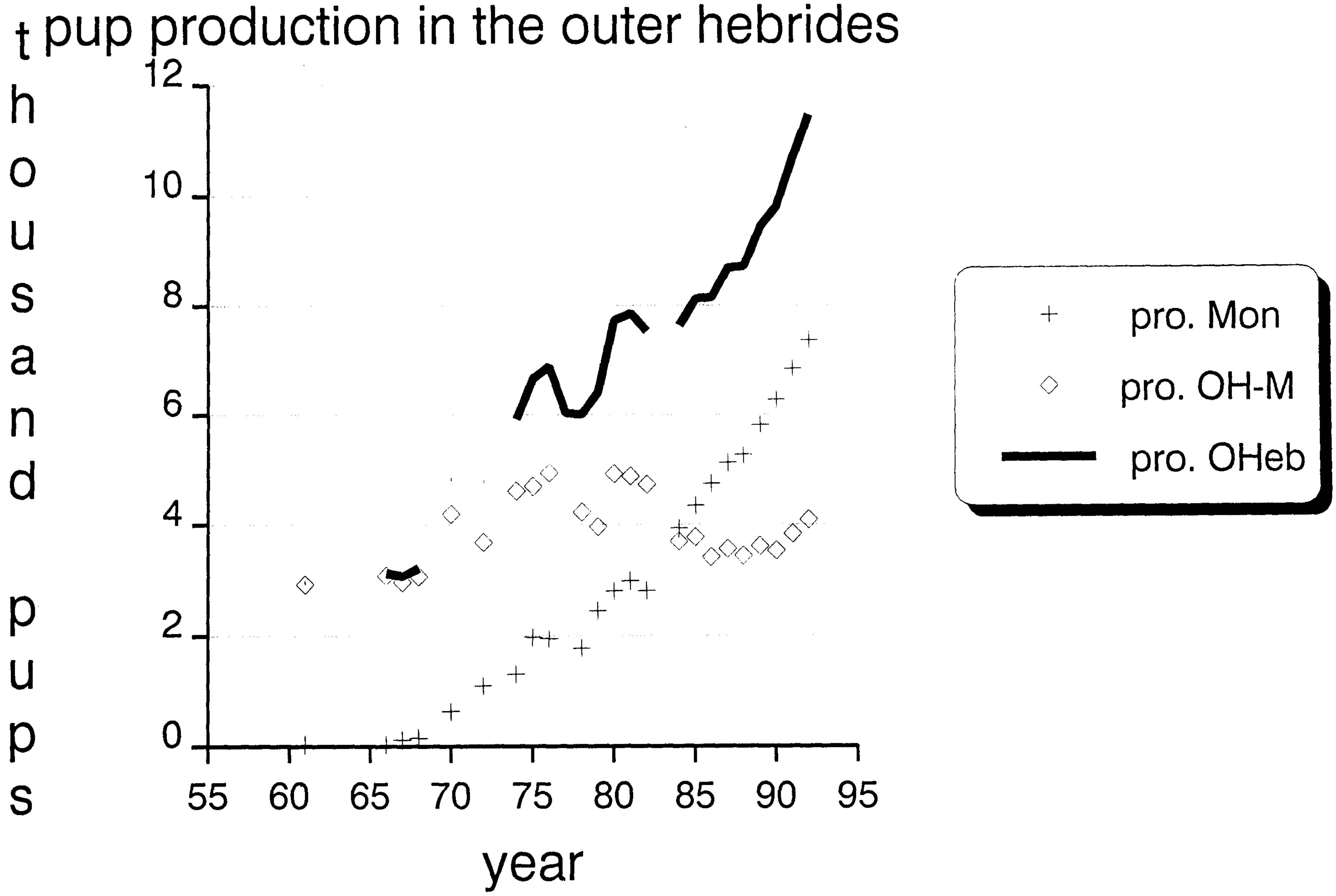

pup production in the outer hebrides
thousand pups
12
10
8
6
4
2
0
55
60
65
70
75
80
85
90
95
year
+ pro. Mon
◇ pro. OH-M
pro. OHeb

FIGURE 6

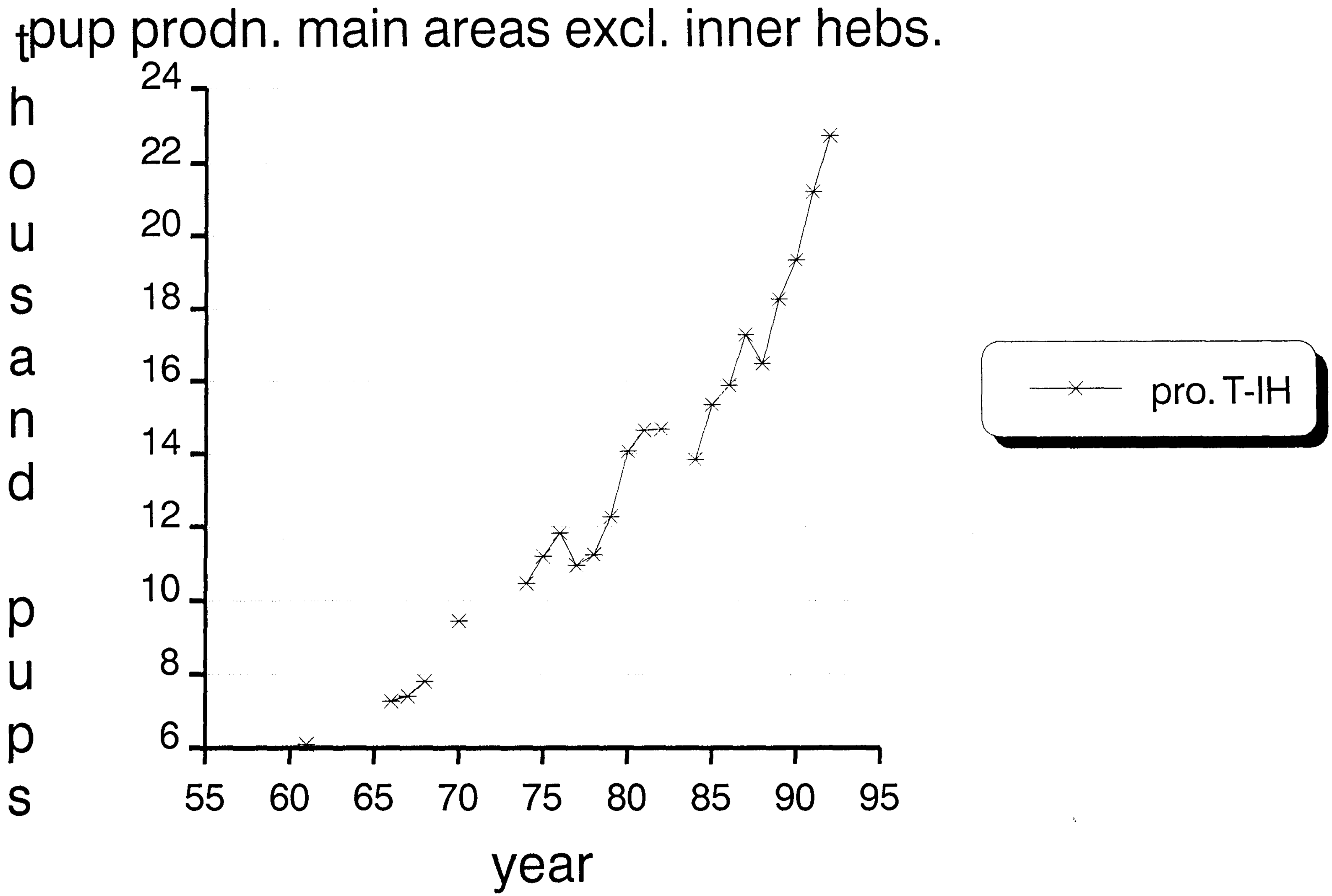

pup prodn. main areas excl. inner hebs.
thousand pups
24
22
20
18
16
14
12
10
8
6
55
60
65
70
75
80
85
90
95
year
pro. T-IH

FIGURE 7

pup production in all main areas

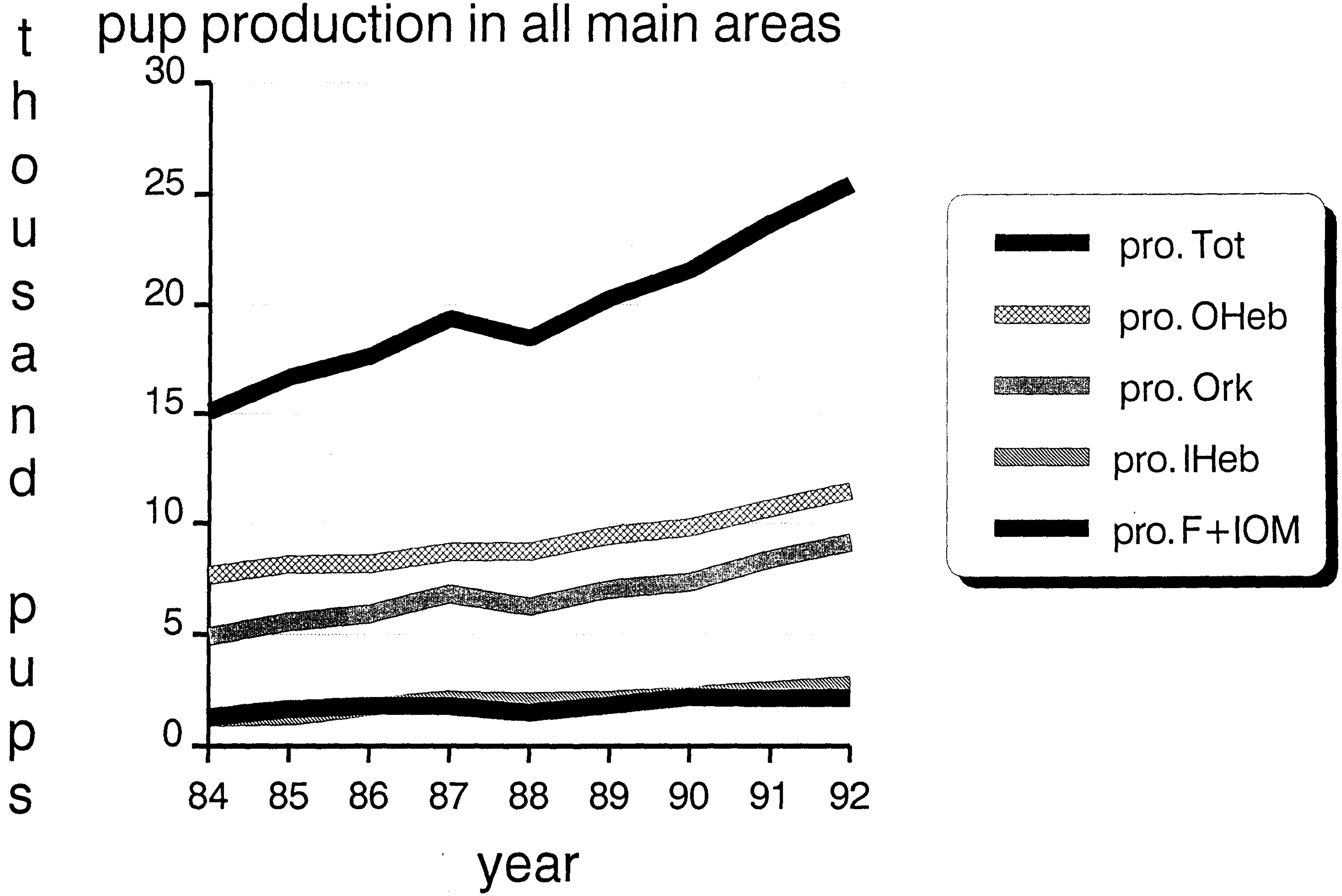


FIGURE 8

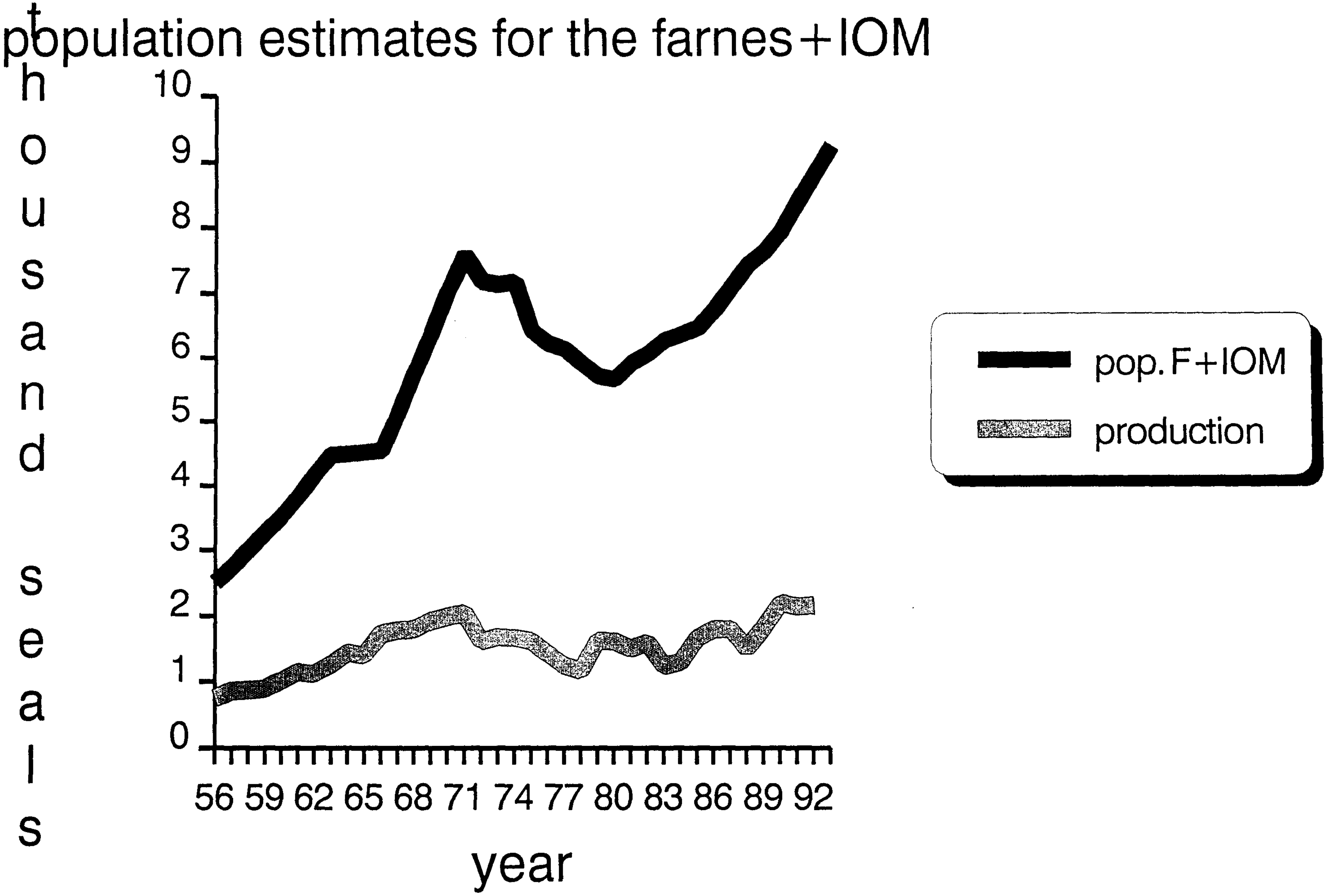

population estimates for the farnes+IOM

FIGURE 9

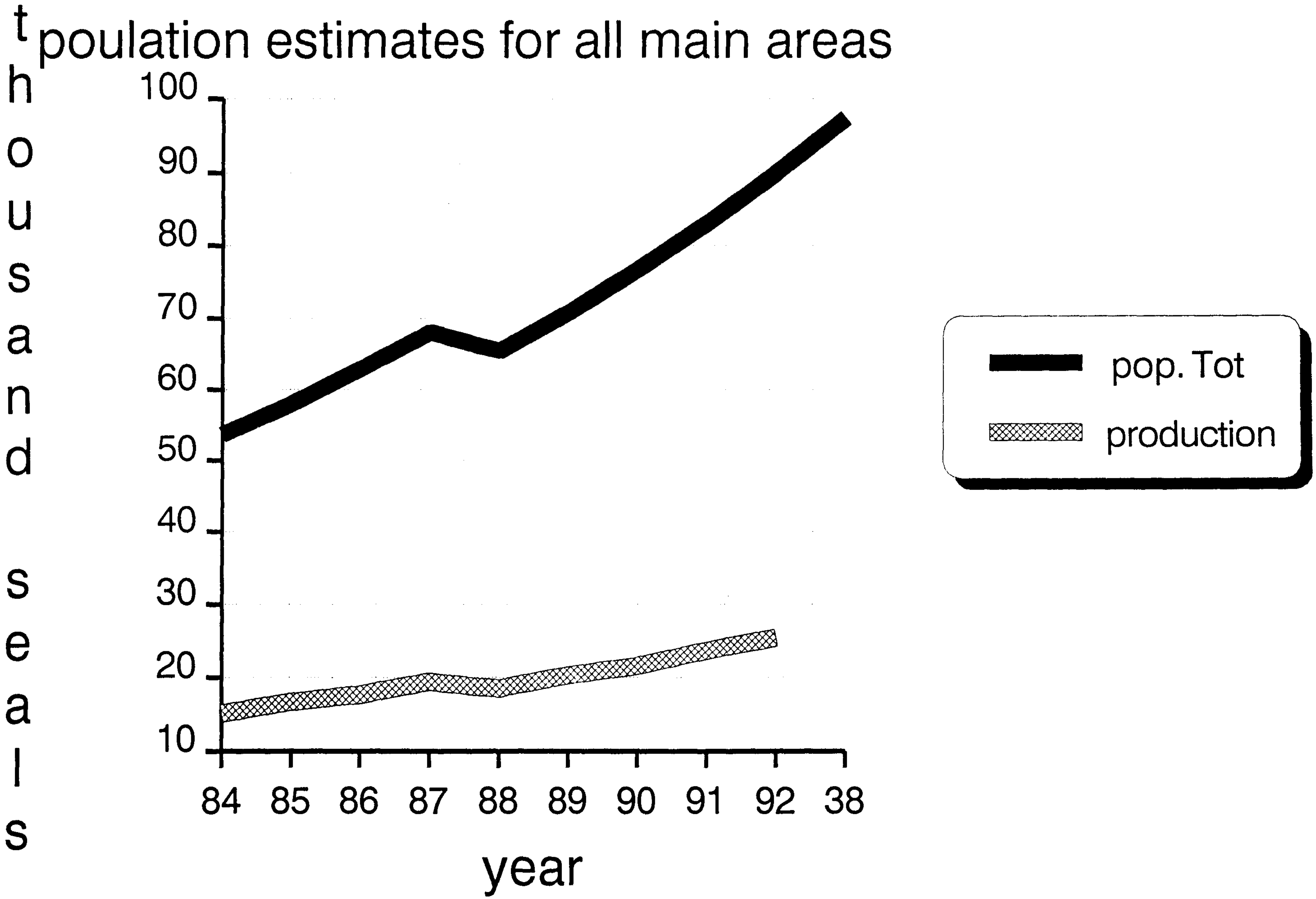
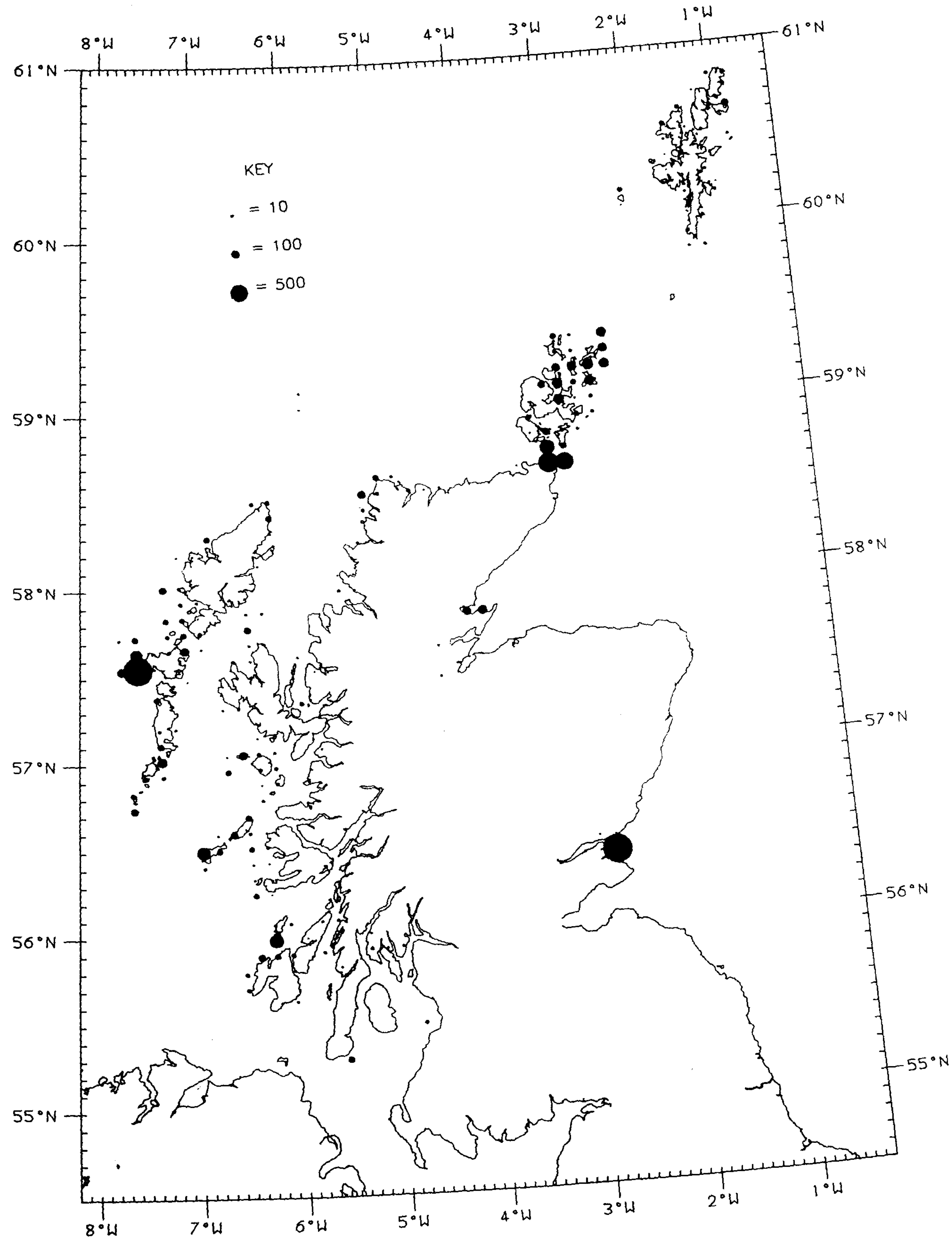
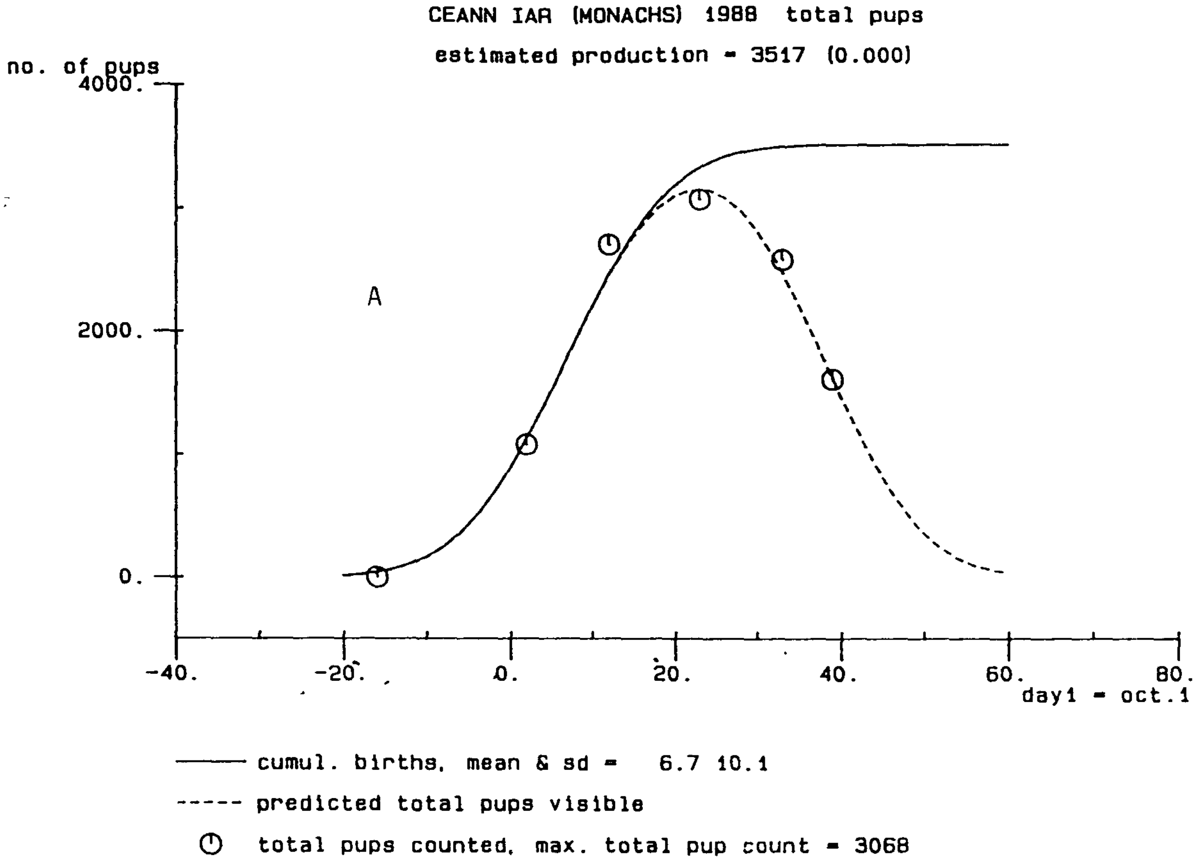

poulation estimates for all main areas
thousand seals
100
90
80
70
60
50
40
30
20
10
84
85
86
87
88
89
90
91
92
38
year
pop. Tot
production

Figure 10 Grey seals in August 1988 - 1992

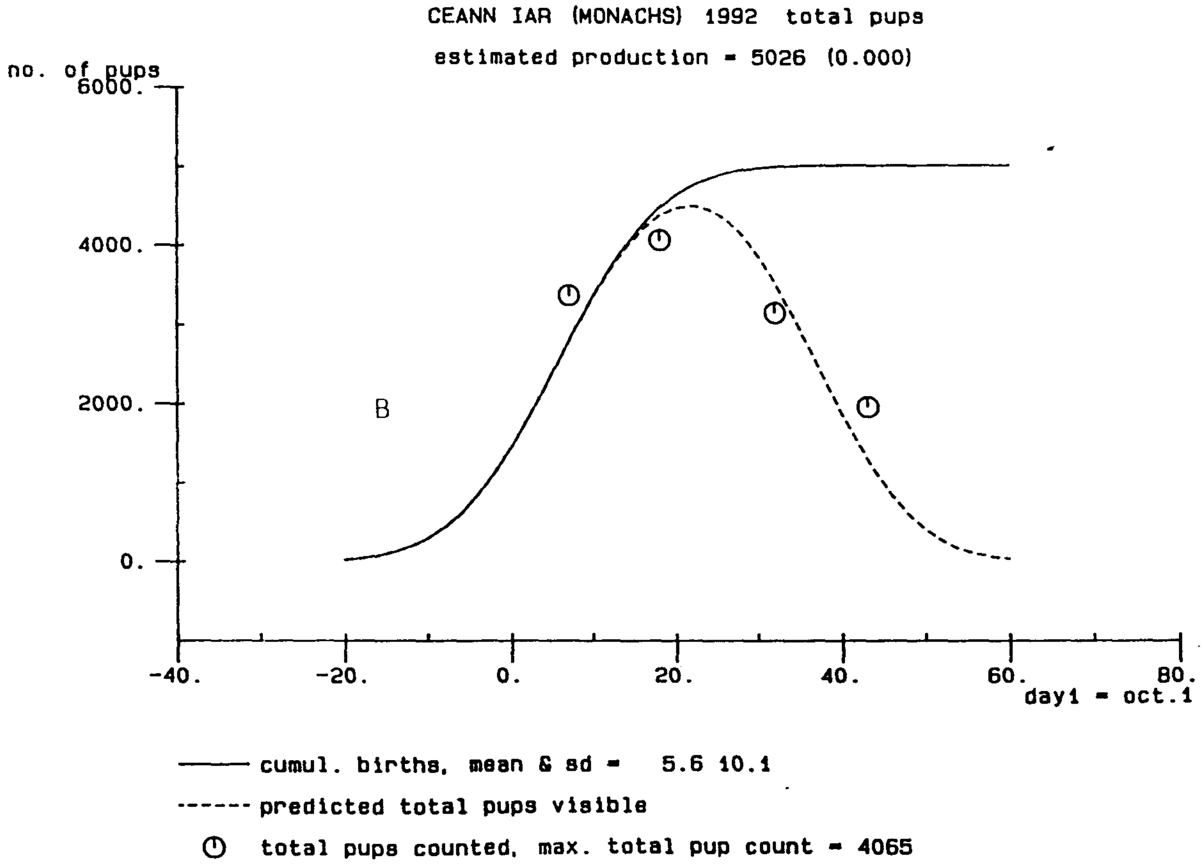


Fiqure 11



CEANN IAR (MONACHS) 1988 total pups

estimated production = 3517 (0.000)



CEANN IAR (MONACHS) 1992 total pups

estimated production = 5026 (0.000)

Figure 12 PUP COUNTS FROM CEANN IAR, MONACH ISLES

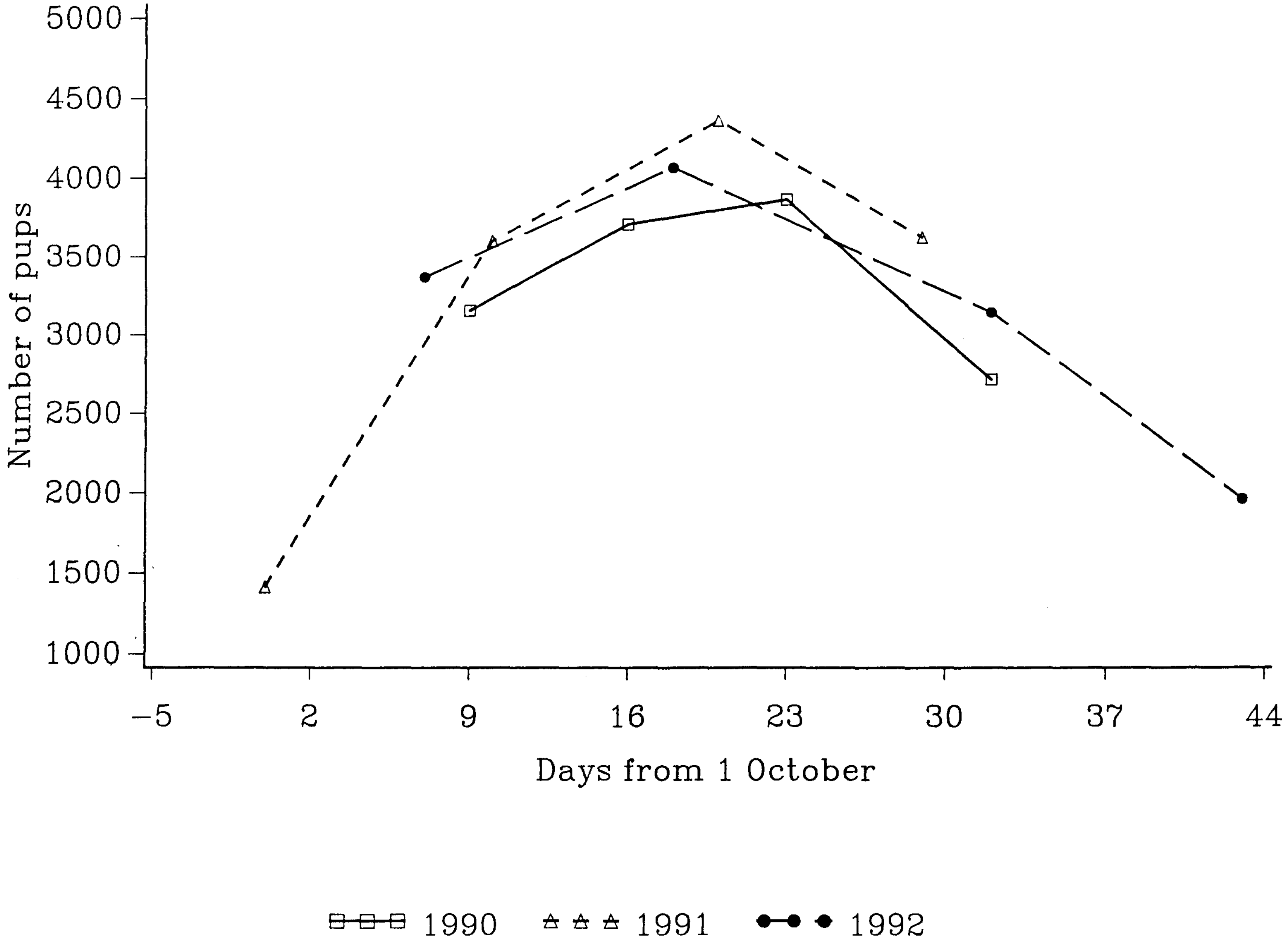


TABLE 1 Pup production estimates for islands in the Inner Hebrides group.

Year	Gunna	Northern Treshnish	Fladda	Sgeir a Chaisteil + Eirionnaich	Lunga	Soa	Eilean nan Ron	Eilean an Eoin	Nave Island	TOTAL
1984	230	82	184	130	168	0	175	225	84	1278
1985	244	86	126	116	162	64	175	289	62	1324
1986	288	109	149	124	196	114	317	323	135	1755
1987	382	109	205	151	236	116	429	326	126	2080
1988	343	145	245	167	252	101	393	222	121	1989
1989	402	131	242	187	286	106	316	181	193	2044
1990	404	133	200	210	267	118	409	302	198	2241
1991	500	160	311	175	264	108	405	382	190	2495
1992	533	188	331	150	320	103	441	412	245	2723

TABLE 2 Pup production estimates for islands in the Outer Hebrides group.

Year	Gasker	Coppay	Shillay (Sound of Harris)	Haskier	Causamul	Deasker	Shivinish (Monachs)	Ceann iar (Monachs)	Ceann ear (Monachs)	Shillay (Monachs)	Stockay (Monachs)	Monachs total **	Others	North Rona	TOTAL
1960	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1961	831	61	114	86	64	13	0	-	-	-	-	38	0	1754	2960
1962	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1963	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1964	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1965	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1966	1063	228	114	101	228	0	0	-	-	-	-	38	0	1350	3122
1967	1063	152	76	101	152	0	0	-	-	-	-	114	0	1417	3075
1968	1063	114	152	101	152	0	0	-	-	-	-	152	0	1485	3219
1969	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1970	1107	320	674	137	97	41	0	0	74	61	496	631	0	1821	4829
1971	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1972	1119	313	571	176	256	67	0	0	239	51	787	1097	0	1178	4778
1973	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1974	1721	283	653	185	211	83	0	50	401	45	813	1308	0	1482	5926
1975	1508	363	595	223	190	51	0	144	602	222	1004	1973	0	1765	6667
1976	1777	390	522	293	205	57	0	114	548	156	1134	1951	0	1697	6892
1977	-	-	-	-	-	-	-	-	-	-	-	-	-	-	6030
1978	1080	318	480	337	163	51	0	571	324	210	675	1780	0	1803	6012
1979	972	373	515	284	150	80	0	685	707	168	890	2450	0	1593	6417
1980	1318	457	749	370	154	31	0	1097	768	247	697	2809	162	1680	7733
1981	1230	418	959	293	168	68	0	1302	424	339	913	2978	136	1606	7857
1982	1415	627	207	338	246	110	0	1353	486	204	767	2809	85	1700	7536
1983	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1984	1063	370	351	323	130	0	83	2197	822	221	617	3940	0	1460	7637
1985	1325	425	307	263	156	0	267	2369	840	189	686	4351	0	1296	8123
1986	1188	353	379	219	100	0	287	2948	703	219	586	4743	0	1178	8160
1987	1298	398	364	245	113	0	356	3267	566	229	709	5127	0	1144	8689
1988	1254	398	350	214	109	0	414	3703	382	184	592	5275	0	1115	8715
1989	1339	415	410	187	90	0	542	4071	424	220	556	5813	0	1175	9429
1990	1387	389	353	157	108	0	568	4595	496	168	450	6277	0	1139	9810
1991	1413	446	395	187	97	0	566	5077	524	187	494	6848	0	1298	10684
1992	1428	409	484	186	111	0	620	5291	620	210	617	7358	0	1482	11458

** Monachs total: Pre-1970 no breakdown available

TABLE 3 Pup production estimates for islands in the Orkney group.

Year	Muckle Green-holm	Little Green-holm	Little Linga	Holm of Spur-ness	Point of Spur-ness	Linga-holm	Holm of Huip	Fara-holm	Faray	Rusk-holm	Wart-holm	Sweyn-holm & Gairsay	Grass-holm	South Ronald-say	Swona	Pentland Skerry	Aus-kerry	Switha	Stroma	TOTAL
1960	724	197	247	99	0	0	0	465	0	214	41	0	0	123	4	99	0	0	0	2213
1961	530	300	259	136	0	0	0	317	0	263	33	0	0	152	4	49	0	0	0	2043
1962	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1963	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1964	921	485	160	29	0	0	0	25	132	214	16	62	4	115	16	25	0	0	0	2204
1965	662	378	288	152	0	0	0	119	169	255	29	25	74	74	21	86	0	0	0	2332
1966	678	469	354	152	0	0	0	284	173	90	8	66	21	107	16	49	0	0	0	2467
1967	592	460	407	107	0	0	0	284	185	259	8	123	0	132	8	37	0	0	0	2602
1968	641	321	411	304	0	16	0	271	288	201	8	90	41	152	29	53	0	0	0	2826
1969	559	308	592	206	8	33	0	226	33	214	4	86	66	127	37	21	0	0	0	2520
1970	736	329	534	148	45	49	25	181	107	230	4	16	74	103	45	86	0	0	0	2712
1971	580	362	728	173	49	156	33	337	99	107	16	78	45	148	70	37	0	0	0	3018
1972	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1973	497	214	534	255	66	201	95	370	41	16	12	95	103	123	53	53	107	0	0	2835
1974	518	197	493	160	21	70	148	526	82	136	0	148	78	136	74	74	103	0	0	2964
1975	477	238	497	296	49	45	127	502	74	66	4	123	25	197	62	49	185	0	0	3016
1976	596	181	666	358	53	78	74	419	95	62	4	218	25	160	95	66	456	0	0	3606
1977	670	218	703	333	78	58	140	502	66	115	4	214	25	156	95	66	243	0	0	3686
1978	329	218	822	514	136	90	206	736	66	226	4	164	41	169	107	58	164	0	86	4136
1979	539	304	354	469	127	164	395	707	103	288	4	156	78	164	95	66	177	0	144	4334
1980	489	173	695	452	107	358	296	859	185	345	0	185	82	140	111	82	119	0	164	4842
1981	436	206	884	489	45	333	547	748	226	329	4	119	103	82	230	127	304	0	210	5422
1982	448	90	736	724	29	370	559	859	164	304	4	115	115	103	152	148	358	164	214	5656
1983	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1984	489	122	542	515	0	328	352	765	560	334	0	130	82	0	81	65	255	162	126	4908
1985	459	218	690	682	0	383	258	803	602	309	0	132	64	0	255	77	303	166	170	5571
1986	560	224	588	538	0	429	378	774	867	348	0	154	85	0	206	68	330	166	211	5926
1987	605	249	704	582	0	556	609	899	998	290	0	116	96	0	327	94	248	173	273	6819
1988	387	181	596	444	0	587	570	873	925	247	0	321	94	0	313	63	244	182	237	6264
1989	449	209	628	457	0	713	621	846	1471	241	0	166	41	0	297	72	306	232	267	7016
1990	379	220	686	380	0	832	736	1036	1346	203	0	197	43	0	409	73	272	229	295	7336
1991	499	201	713	389	0	1099	869	947	1704	182	0	205	74	0	471	74	280	270	398	8375
1992	496	201	798	424	0	1149	974	1221	1824	196	0	204	48	0	530	65	210	290	486	9116

TABLE 4 Pup production estimates for sites other than those covered by aerial surveys. See figure 1 for location of sites.

Year	Farne Islands	Isle of May	SW England	Wales	Donna Nook	Helmsdale	Eriboll	Shetland
1956	751	-	-	-	-	-	-	-
1957	854	-	-	-	-	-	-	-
1958	869	-	-	-	-	-	-	-
1959	898	-	-	-	-	-	-	-
1960	1020	-	-	-	-	-	-	-
1961	1141	-	-	-	-	-	-	-
1962	1118	-	-	-	-	-	-	-
1963	1259	-	-	-	-	-	-	-
1964	1439	-	-	-	-	-	-	-
1965	1404	-	-	-	-	-	-	-
1966	1728	-	-	-	-	-	-	-
1967	1779	-	-	-	-	-	-	-
1968	1800	-	-	-	-	-	-	-
1969	1919	-	-	-	-	-	-	-
1970	1987	-	-	-	15	-	-	-
1971	2041	-	-	-	1	-	-	-
1972	1617	-	-	-	0	-	-	-
1973	1678	-	107	-	0	-	-	578
1974	1668	-	-	-	-	-	-	-
1975	1617	-	-	-	-	-	-	-
1976	1426	-	-	-	-	-	-	-
1977	1243	-	-	645	-	-	-	700
1978	1162	-	-	-	-	-	-	-
1979	1320	300	-	-	-	-	-	-
1980	1118	499	-	-	-	-	-	-
1981	992	505	-	-	34	-	-	-
1982	991	603	-	-	43	-	-	-
1983	902	336	-	-	-	-	-	-
1984	778	517	-	-	30	94	406	-
1985	848	810	-	-	53	-	-	-
1986	908	891	-	-	35	-	-	-
1987	930	865	-	-	72	-	-	-
1988	812	690	-	-	54	-	-	-
1989	892	935	-	-	94	280	666	-
1990	1004	1185	-	-	152	-	-	-
1991	927	1218	-	-	223	321	-	-
1992	985	1169	-	1450	200	225	612(air)	-

TABLE 5 Estimated size of the population associated with all major grey seal breeding sites in Scotland and Northumberland except Loch Eriboll, Helmsdale and the Shetlands. Estimates refer to the number of seals of age 1 and over at the time of the breeding season.

Year	Pup Production	Female Population	Female + Male Population
1984	15118	30559	53656
1985	16676	33062	58046
1986	17640	35851	62957
1987	19383	38764	68059
1988	18470	37291	65478
1989	20316	40352	70853
1990	21576	43747	76812
1991	23699	47314	83078
1992	25451	51264	90017
1993		55486	97435

TABLE 6

Declared number of grey seals killed under licence in Great Britain between 1970 and 1992, including those taken under scientific permit. All figures refer to pups unless otherwise indicated.

Year	Orkney and east coast	Outer Hebrides	Shetland	Farne Islands
1970	726 + 5 ad		60	6
1971	975	5 + 6 ad	31 + 8 ad	5 + 12 ad
1972	699	7	30	581 + 748 ad
1973	837 + 4 ad	386	49	3 + 17 ad
1974	975	868	73	4 + 5 ad
1975	1050	754	68	804 + 663 ad
1976	1010 + 10 ad	600	72	4 + 4 ad
1977	841	394 + 324 ad	10	209 + 134 ad
1978	1067	85	59	117 + 58 ad
1979	1015	200 + 1 ad	37	137 + 80 ad
1980	1195	7 ad	40	35 + 58 ad
1981	1200 + 19 ad*	2 ad	40	64 + 162 ad
1982	1166 + 18 ad*	-	49	134 + 54 ad
1983	8 ad*	-	1 ad*	24 + 4 ad
1984	2 ad*	-	1 ad*	37
1985	1 ad*	4 ad* + 1 ad		37
1986	2 ad*	-		31
1987	21 ad*	15 ad*		13
1988	-	-		-
1989	-	-		-
1990	-	-		18
1991	-	-		12 + 1 ad
1992	1 ad			10 + 3 ad

* taken by fishermen or fish farmers

Appendix 1:

Estimates of population size and related parameters for the Farne Islands' grey seal population.

A.R. Hiby

SUMMARY

This report describes an attempt to estimate the trajectory of population size of female grey seals at the Farnes since 1956 and to place confidence intervals on the estimate for 1972. In order to avoid introducing previously estimated population sizes, and thereby introducing an unknown degree of uncertainty into the population size estimates, the method attempts to estimate simultaneously all parameters and population sizes from all the available data using a maximum likelihood approach. Confidence limits are then placed on the 1972 population estimate using the likelihood ratio method. The validity of the application of this method in this case is investigated using simulation studies. These are also used to investigate the effect on the estimation procedure of violating some of the many assumptions required to construct a model of population growth involving a manageable number of parameters.

INTRODUCTION

This report describes a procedure which has been used to estimate the size of the grey seal population associated with the Farne Islands (defined as the number of females of age one and over that were born at the Farne Islands, or the Isle of May, and which are alive at the time of the breeding season in each year) from 1956 to 1982, and the confidence regions for these estimates.

This procedure uses the following data:-

(1) The number of pups born each year from 1956 to 1982 (p_t, where t = 56, ..., 82).

(2) The number of female pups killed each year in management culls.

(3) The number of adult females killed each year in these culls.

(4) The ages of all the animals killed. The large culls of 1972 and 1975 did not take representative samples of the population. This is because the number of seals taken on each island were not in proportion to the size of the population on that island. The age structures of these culls have been processed to give random samples of the population age structure in those years, for animals above the age (i_o) at which they appear to be fully represented in the culls. (C_t is the total number of females above this age in the cull in year t, and $c_{i,t}$ is the number in each age class - $i = i_o, ..., 29$).

(5) Observations from a sample of 52 sexually mature females take in 1981, 49 of which were pregnant.

A mathematical model of the growth of the female section of the Farnes' population is used to give a joint probability density for these data, conditional on a number of unknown parameters. This probability density function is then maximised with respect to these parameters to give maximum likelihood estimates. The parameters are then used to estimate population size in each year.

The following notation is used in the model:-

$n_{i,t}$ - number of females aged i alive in the population at the time of the breeding season in year t - before any culls have take place.

$n_{29,t}$ - number of females age 29 and over in year t.

P_t - total female population in year t (i.e. $P_t = \sum_{i=1}^{29} n_{i,t}$).

S_j - survival of natural mortality from birth to age 1.

S - annual survival for all other age classes (note that $n_{29,t+1} = S(n_{28,t} + n_{29,t})$).

F - average number of offspring produced each year by a female aged 7 or above. Age-specific fecundities for age classes under 7 are taken from Harwood and Prime (1978, J. appl. Ecol. 15: 401-11), except that the small number of females which reproduce at age 4 is ignored.

To obtain $n_{1,t+1}$ the observed number of pups born in year t (pt) is divided by two (to give the number of female pups) and multiplied by 0.8 (to allow for deaths from natural mortality before the pups culls); the number of female pups killed in year t is then subtracted from this and the resulting figure is multiplied by $S_j/0.8$.

Given starting values for S_j & S, the set of observed pup productions and an initial age vector the model will generate a series of age vectors for all subsequent years. The age vector in 1956 was calculated by assuming that the population had attained a stable age distribution. Thus the procedure estimates the parameters S_j, S, λ (the annual rate of increase of population) and P_t by fitting the model to the available data.

Up to this point the model is entirely deterministic. The effect of ignoring stochasticity in, for example, the proportion of seals of each age surviving natural mortality, and in the sex ratio of newborn pups, was investigated by using simulation models of population growth, described in a later section.

We now describe how the model is used to determine the joint probability density function for the available data, conditional on the unknown parameters. The model defines the expectation of each data point, the density then follows from assumptions concerning the variability in pup production and sampling variability in the structure of adult culls.

Expected pup production in each year, conditional on the parameters and earlier observed pup productions, is obtained by applying age specific fecundities to the age structure generated by the model for that year. To obtain age specific fecundities we assume that once a female has had a pup the probability she has a pup in each subsequent year is independent of age and independent from year to year. The proportion of females having their first pup at each age has been determined by studies of tooth growth rings in adult seals (Harwood & Prime, 1978).

Using those results we have the expected pup production in t:

$$E(p_t) = 0.16\, n_{5,t} + (0.45 + 0.16F)\, n_{6,t} + \sum_{i_o}^{29} \frac{Fn_{i,t}}{2}$$

where F, the mean fecundity for sexually mature females, is a further parameter to be estimated. In fact F replaces S_j as an independent parameter for, once S, λ and F are specified, S_j is easily determined using a balance equation for growth of a population with a stable age structure.

The probability density of p_t, conditional on earlier pup productions, is obtained by assuming p_t is normally distributed about $E(p_t)$ with standard deviation σ_t, i.e:

$$f\ (p_t \mid p_{56} \cdots p_{t-1}, \underline{\theta}) = N\ (E(p_t \mid p_{56} \cdots p_{t-1}, \underline{\theta})\ ,\ \sigma_t)$$

where $\underline{\theta}$ is the vector of parameters S, λ, P_{56} and F.

The joint probability density for p_{56}, p_{57} ... p_t is then obtained by multiplying the conditional density by the joint density for p_{56}, p_{57}, ... p_{t-1}. Only pup productions before 1972 are used. This is because adult culls starting in 1972 have caused a drop in observed pup productions which is larger than would be expected purely as a result of the number of mature females killed, and which is probably due to emigration to other breeding sites. There is no provision in the model for reproducing this effect.

σ^2_t gives the expected squared difference between predicted and observed pup productions in year t. In the results given in this report we have taken σ^2_t to be constant at σ^2. We have also repeated the estimation procedure with σ_t proportional to $E(p_t)$. This gave very similar results.

We cannot write down the joint density for pup productions from 1956 to 1971, which will form the first term in the likelihood function:

$$L_1 \; (\underline{\theta}, \sigma \mid p_{56} \cdots p_{71}) = \prod_{t=56}^{71} \frac{1}{\sqrt{2\pi\sigma^2}} \exp\left\{-\frac{1}{2\sigma^2} \left(E(p_t \mid p_{56} \cdots p_{71}, \underline{\theta}) - p_t \right)^2\right\}$$

To extend the likelihood function to include data from the 1972 and 1975 culls of adult females, we need the expected age class frequencies conditional on the model parameters and earlier pup productions. Let i_o represent the minimum age at which females are fully represented in the breeding beach culls, C_t the total number of females of age i_o or over killed in year t, and $c_{j,t}$, the number of females of age j killed in year t. The expectation of $c_{j,t}$ conditional on model parameters and earlier pup productions and culls is:

$$E(c_{j,t}) = C_t \frac{n_{jt}}{\sum_{i=i_o}^{29} n_{i,t}}$$

This is only valid for t = 75 if we assume that the 1972 cull did not effect the age structure of the population, except by the removal of the animals killed in 1972 from each age class. Assuming the culls represent random samples, the probability distribution for $C_{i_o,t}$ to $C_{29,t}$ is multinomial. This gives the joint probability distribution for the age structured culls is 1972 and 1975, which forms the second term in the likelihood function:

$$L_2\left(\underline{\theta} \mid c_{i_o,72} \cdots c_{29,72} \; ; \; c_{i_o,75} \cdots c_{29,75}\right)$$

$$= \frac{C_{72}\,!}{c_{i_o,72} \cdots c_{29,72}} \prod_{j=i_o}^{29} \left(\frac{n_{j,72}}{\sum_{i=i_o}^{29} n_{i,72}} \right)^{c_{j,72}} \cdot \frac{C_{75}\,!}{c_{i_o,75} \cdots c_{29,75}} \prod_{k=i_o}^{29} \left(\frac{n_{k,75}}{\sum_{i=i_o}^{29} n_{i,75}} \right)^{c_{k,75}}$$

Lastly we extend the likelihood function to include the results of a sample of 52 sexually mature females taken before the breeding season in 1981. Let n_p represent the number of females found to be pregnant, and let a further parameter M represent the number of sexually mature females in the population breeding at the Farnes in 1981. Note that M is not simply that part of the total female population in 1981 which is sexually mature because, following the 1972 and 1975 culls, a proportion of the sexually mature females which have been born at the Farne Islands no longer breed there. Then the pregnancy rate in the population at the Farnes in 1981 was p_{81}/M and, assuming the cull was a random sample, the distribution of n_p is binomial, $B(52, p_{81}/M)$. Furthermore, assuming the breeding season culls have not effected the fecundity of sexually mature females in the population remaining at the Farnes, the expected pup production in 1981 is:

$$E(p_{81}) = FM$$

and the density of p_{81} is normal, $N(FM,\sigma)$. So for the last term in the likelihood function we have:

$$L_3 \; (F, M, \sigma \mid p_{81}, n_p)$$

$$= \frac{1}{\sqrt{2\pi\sigma^2}} \exp \; -1/2\sigma^2 \, (FM - p_{81})^2 \cdot \frac{52\,!}{n_p\,!\,(52-n_p)\,!} \left(\frac{p_{81}}{M}\right)^{n_p} \left(1 - \frac{p_{81}}{M}\right)^{52-n_p}$$

The introduction of this term is necessary to restrict the possible range of values for the parameter F. It is not equivalent to simply using the proportion of pregnant females in the sample, to estimate F because of the year to year variation in pregnancy rate.

The likelihood function incorporating all the data is

$$L\left(\underline{\theta}, \sigma, M \mid p_{56} \cdots p_{71}, p_{81}, c_{i_o,72} \cdots c_{29,72}, c_{i_o,75} \cdots c_{29,75}, n_p\right) = L_1 \cdot L_2 \cdot L_3$$

MAXIMISING THE LIKELIHOOD FUNCTION

By differentiating log L with respect to σ and equating to 0 we obtain:

$$\hat{\sigma}^2 = \frac{1}{17}\left[\sum_{t=56}^{71}\left(E\left(p_t \mid \underline{\theta}\right) - p_t\right)^2 + \left(\hat{F}\hat{M} - p_{81}\right)^2\right] = \frac{SS}{17}$$

where SS is the sum of squares of differences between observed and expected pup productions in years 1956 to 1971 and 1981.

Substituting $\hat{\sigma}^2$ back into log L and eliminating all terms not including any of the parameters we obtain:

$$\log L \;\alpha\; -\frac{17}{2}\log SS + \sum_{j=i_o}^{29} c_{j,72}\log\left(\frac{n_{j,72}}{\sum_{i=i_o}^{29} n_{i,72}}\right) + \sum_{k=i_o}^{29} c_{k,75}\log\left(\frac{n_{k,75}}{\sum_{i=i_o}^{29} n_{k,75}}\right) + n_p\log\left(\frac{p_{81}}{M}\right) + (52 - n_p)\log\left(1 - \frac{p_{81}}{M}\right)$$

This expression was maximised with respect to $\underline{\theta}$ (λ, S, P_{56} and F) and M using initial estimates and a simplex routine. At each iteration the population growth model is run, using the parameter value attained by that stage, to generate the expectations of p_t, $c_{i,t}$ and n_p conditional on those parameter values. This procedure also generates the age-structured trajectory of the female population corresponding to each set of parameter values used and, in particular, the trajectory corresponding to the maximum likelihood estimates of the parameters. Because the female pup productions are assumed to known without error, and the population growth model, given the pup production, is deterministic, any element of the age-structured trajectory is a functions of the parameters, and is thus a maximum likelihood estimate of the corresponding element in the real population. In particular, the procedure gives maximum likelihood estimates for the total female population in each year.

RESULTS

The maximum likelihood estimates for the initial rate of population growth λ, the annual survival rate for females aged 1 year and over •, the mean fecundity for sexually mature females F, and the number of sexually mature females in the population breeding at the Farnes in 1981 are as follows:-

$\hat{\lambda}$ = 1.0787
$\hat{S}$ = 0.98
$\hat{F}$ = 0.94
$\hat{M}$ = 1597

In addition, we have, from the balance equation, the survival of pups from birth to age 1, excluding the effect of pup culls:

$$\hat{S}_j = 0.34$$

The estimated trajectory of total female population size from 1956 to 1981, $P_{56} \ldots P_{81}$, is shown in Fig 1a.

Up to 1972 the estimates refer to the female population local to the Farnes, i.e. females actually or potentially breeding at the Farnes. This is implicit in the way expected pup production is linked by age-specific fecundity to 'the population' in the model. This means that if any females emigrated from the Farnes to breed elsewhere before 1972, then the parameter S refers to the proportion surviving natural mortality and emigration, rather than natural mortality only. From 1972 onwards it is clear that a significant number of females have left the Farnes population. The trajectory beyond 1972 thus refers to a population which would still be breeding at the Farnes if the culls had not taken place, but which is now partly located elsewhere. The situation is simplified if we assume that no significant migration occurred before 1972, so that S refers solely to survival of natural mortality, and that the rate of natural mortality did not change as a result of the culls. In that case all the population estimates P refer to the number of females alive in year t which have been born at the Farnes, and which before 1972 were all at the Farnes but which are now more widely dispersed. It is unlikely, given the high value of the S estimate, that significant emigration occurred before 1972.

Confidence Limits for P_{72}

We have attempted to assess the reliability of this procedure for estimation of population size by deriving confidence limits on the estimate for 1972, the last year for which the estimates apply to the local population.

It is possible to obtain an indication of the reliability of the P_{72} estimate by noting to what degree the fit of the model to the data is impaired when the population trajectory is constrained to pass through a different value in 1972.

Let $P_{72,o}$ be any value for the size of the model female population in 1972 and $\underline{\hat{\theta}},\underline{\hat{M}}$ the maximum likelihood estimates obtained when the model is constrained to pass through $P_{72,o}$.

Denote by L.R. the ratio

$$L\,(\underline{\hat{\theta}},\hat{M}) \;/\; L\,(\underline{\hat{\theta}},\hat{M})$$

where L is the likelihood and $\underline{\hat{\theta}}$ and $\hat{M}$ are the m.l. estimates in the non-constrained case. Under

$$H_o : P_{72} = P_{72,o},$$

-2 log (L.R.) is distributed asymptotically as χ^2_ν where ν is the number of constraints imposed, i.e. 1 in this case.

This was used to construct a 95% confidence interval for P_{72}. Values $\hat{P}_{72,u}$ and $\hat{P}_{72,l}$ were found for which -2 log (L.R.) was equal to the 95% critical level of the χ^2_1 distribution. This is a 95% interval because the interval $(\hat{P}_{72,l}, \hat{P}_{72,u})$ can only fail to include the true 1972 population size, say $P_{72,o}$ if -2 log (L.R.) exceeds $\chi^2_{1,95}$ which has probability .05.

The confidence interval resulting from this procedure was (3100, 5600).
We were not certain whether the conditions required for use of the distribution were fulfilled by our data, in particular, whether the data set is sufficiently large to invoke asymptotic properties of m.l. estimators. In the next section we describe the simulation studies carried out to investigate the effects of violating some of the model assumptions on the estimation procedure. These also provide a test of the validity of the method used to construct confidence limits. The results suggest that the procedure used to set confidence limits does produce a 95% confidence interval, at least when the assumptions of the model are not violated.

Violation of Model Assumptions

A large number of assumptions have been made in order to formulate a model of population growth and hence estimate population size in each year. One assumption, namely that concerning emigration from the Farnes population, has been discussed in the preceding section. We now consider two other assumptions and investigate what effect their violation may have on the estimation procedure.

1. *Stable age structure.*

A starting age vector is required to initiate modelling of population growth and it was assumed that in 1956 the population had attained a stable age structure. The need for this assumption can be simply overcome by eliminating the observed pup production in years 1956 to 1962 from the likelihood function. From this time on the population age structure, as far as it effects expected pup production, is entirely determined by earlier observed pup production. At the same time, the cull data from 1972 and 1975 is eliminated from the likelihood function because the expected age class frequencies deprive largely from the structure of the starting age vector. The resulting parameter estimates are:

$\hat{S} = 0.95$

$\hat{F} = 0.94$

$\hat{M} = 1590$

and $\hat{S}_j = 0.51$

The estimated population trajectory is shown in Fig. 1b, and the 95% confidence interval for P_{72} is (3000, 6800). The estimates are generally similar to those obtained above except that the 'adult' and 'juvenile' survival parameters are lower and higher respectively and more similar to the value 0.935 for adult survival suggested by Harwood & Prime (J. appl. Ecol., 15 : 401-411). The population estimate for 1972 is higher, at 4637 as compared to 3971 when using the stable starting age structure assumption. As expected the confidence interval is wider but encompasses the previous interval.

2. *Survival rates and sex ratio*

In the model used in the estimation procedure the proportion of pups and 'adults' surviving natural mortality is exactly S_j and S each year, constant with time and independent of age, and exactly half the pups born each year are females. These assumptions permit a very simple model structure but are clearly unrealistic. There must be at least binomial variation in the proportions surviving per year and in the sex ratio of newborn pups. The effect of ignoring this variation has been investigated using data generated by simulation model of population growth identical to that envisaged in the estimation procedure.

Date is generated by the simulation model by adding random error from appropriate distributions to expected pup productions in 1956 to 1981 and a sample of 52 'animals' is taken from the simulated population to estimate pregnancy rate in 1981, as for the real population. These data are subjected to the same estimation procedure as applied to the data from the real population, and the estimates of parameters compared to the parameter values used to drive to simulation. The procedure was repeated many times to identify and biases in the estimates and to see in what proportion of runs the confidence interval for the 1972 population size failed to include the value attained in the simulation.

No significant biases were observed in the average results of several hundred runs. As the proportion of confidence intervals for P_{72} failing to include the true value, the results were as follows:

a. When the simulation model was exactly as envisaged in the estimation procedure, with no stochasticity in survival rates or sex ratio, about 5% of P_{72} confidence intervals failed to include the value attained in the simulation.

b. The failure rate increased to 10-15% when binomial variation was included in survival rate for each age class and sex ratio of newborn pups.

c. The rate increased to around 40% when, in addition to binomial variation, a year to year variation in survival rate was imposed by using, for year t, a value for S_t normally distributed about S with standard deviation 0.02. Such a level of variation in survival rate may well apply in the real population.

Variation in survival rate induces positive serial correlation in the error term for p_t about $E(p_t)$ - about 0.2 in case (b) and 0.5 in case (c) - which in turns leads to an underestimate in the width of the confidence interval. Judging by the residuals of the seal pup productions about the fitted model such serial correlation is not apparent in the real population, but estimated serial correlations based on such a short series of available data are subject to high variance and the situation is still uncertain.

SCOS

British Grey Seal Pup Production Estimate for 1993

- status report by A R Hiby and C Duck

Background

Our last report to SCOS on grey seal production expressed doubts concerning the ability of the estimation procedure used since 1984 to monitor changes in grey seal pup production accurately. This report describes the measures being taken to ensure that current and future production estimates can be compared to those in each year since 1984.

Up to an including 1991 the number of pups visible on the 3-4 successive surveys of each island could be matched quite closely by a simple model which assumed that births were normally distributed about a mean date specific to each island in each year. The mean length of time for which pups remain on the breeding beach to be counted was based on observations of known-age pups at the Isle of May. The spread of the birth curve was taken as constant at a standard deviation of 10 days for each island. A maximum likelihood estimated for total births on each island was derived from this model. Summed over all islands these estimates suggested an annual increase of about 7% since 1984.

The model fit to the counts obtained in 1992 was less satisfactory. For many islands the pups-on-the-beach curve generated by the model was too narrow. This suggested that the standard deviation of the model birth curve should be increased. However, there was also more skew to the right in the observed counts than in the model.

Results in 1993

During the 1993 breeding season, a minimum of 6 aerial photographic surveys were conducted over each major breeding site in the Hebrides and Orkney. These counts confirmed the impression gained in 1992 that the model is no longer adequate. Figure 1 illustrates counts and model fits for islands in the Outer Hebrides in 1993. Figure 2 illustrates the changes since 1988, when 5 surveys were completed and the fit seemed adequate, for Gasker, which is the first island shown in Figure 1.

The series of observed counts at each island in 1993 can be reproduced by assuming that births are lognormally distributed by moving with a standard deviation "free" to fit the observations. But this requires the fitting of 4 rather than 2 free parameters. This is not possible with the number of counts obtained before 1993. Another problem is that this approach attributes all of the apparent increase in the length of the season to change in the birth curve. There may also be changes in the time for which pups remain visible. For example, pup mortality affects the apparent length of the season via the time the pup remains visible. Pups which die during the first few days of life will disappear quickly and reduce the mean time for which pups remain visible, those that die later may remain for weeks and increase the mean time for which pups remain visible. Pup mortality may increase as the production on an island approaches its carrying capacity. If this increases the mean time for which pups remain visible, it is important that the estimation technique should not misinterpret that as an increase in the spread of the birth curve.

These apparently subtle changes in the length of the pupping season and the way it is accounted for can have profound effects on estimates of changes in the number of pups born from year to year. For example, fitting a lognormal distribution with a "free" standard deviation to the 1992 counts leads to an estimate which is much higher than that for 1991. However, if it is assumed that there was no change in the distribution of births between 1991 and 1992, the estimates of pup production for the two years are very similar.

To address these problems we need to enhance the information from the photographs. The increase in the number of surveys in 1993 is one solution, but all photographs from previous surveys have already been counted. Another solution is to consider each count in more detail. In all but one year, pups have been classified into fully-moulted and white-or-moulting classes. We avoided using the classified counts in the past because of potential misclassification errors, but we are not trying to quantify the degree of misclassification. A third option is to derive additional statistics from the photographs. The number of pups sucking at the time of the flight was also counted on the 1993 photographs. The proportion of pups suckling helps to determine the timing of the birth curve and should also respond to the level of mortality and desertion of pups by mothers pre-weaning.

Revised estimation model

The estimation procedure is being revised to incorporate classified counts and counts of suckling pups, and to exploit the increase in the number of surveys in 1993. By identifying which parameters of the model are constant and estimable from independent observations (eg. time to moult, time to weaning), and which vary with location (eg. the time for which dead pups remain visible) and time (eg. mortality rate of pups) we hope to enhance the ability of the estimation model to monitor changes in pup production. It may be necessary to obtain counts of suckling pups from some of the earlier photographs.

The current model is driven by calculating the probability that a pup which is born at some time during the season will be visible at each flight and at both of any pair of flights. This in turn generates the expected vector for the number of pups visible at each flight and its variance-covariance matrix. For the revised model the vector is extended to hold the number of white, fully moulted and suckling pups counted on each flight. We therefore need the probabilities that a pup is in each of these states at the time of each flight and in any pair of states on any pair of flights (some pairs have zero probability, eg. moulted at one flight and whitecoat at a later flight). The coding which derives the production estimate given these probabilities are not. Those models should be based on the maximum amount of independent information and the minimum number of free parameters to be estimated from the counts.

Implications for 1994 meeting of SCOS

Given the problems described above, it will not be possible to provide reliable estimates of grey seal numbers for the 1993 in time for the meeting of SCOS planned for the end of June. If the meeting is postponed until the end of July, we should have a good idea of how to obtain the best estimate from the 1993 survey. However, in order to generate the time series of pup productions needed to estimate total population size, it will be necessary to apply the same procedure to all the historical counts. In addition, if may be necessary to recount some, and possibly all, the historical photographs.

The earliest such a complete series could be available is early September.

Scos File R49/93

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SCOS93/2
ANNEX II

ADVICE ON THE STATUS OF BRITISH COMMON SEAL POPULATIONS: 1993

Annex II (Duck *et al.*, in prep.) summarizes the methods used to count British common seals. It also contains detailed maps of the distribution of sites in Scotland and on the east coast of England which common seals use for hauling-out in August. Significant changes made to Duck *et al.* since 1992 are shown in bold type.

Until 1984, SMRU estimated the abundance of common seals by counting the number of animals hauled-out in particular regions from boats, in July at the end of the pupping season. However, estimates from such surveys are not sufficiently precise or accurate to provide a useful indication of the status of British common seal populations. Throughout Europe, surveys of common seals are now carried out between late July and mid-August, when the largest number of seals are usually recorded and repeat counts of the same areas give consistent results. Where counts from boats at the end of the pupping season and from aircraft in August have been carried out in the same year, approximately twice as many seals have been counted from the air. Even though counts made in early August are usually higher than those made at any other time, it is still unlikely that all members of the population will be visible. Thus the figures in this advice represent the minimum number of seals in each area surveyed. The relationship between this minimum number and total population size has not been established precisely. However, studies of seals in Orkney fitted with radio transmitters have indicated that almost all males and 42-75% of females are likely to be counted during aerial surveys in August. If the behaviour of seals elsewhere in Britain is similar to that observed in Orkney, total population sizes could be 23-59% higher than these values.

In 1992, SMRU carried out aerial surveys of common seals in the Outer Hebrides, Solway Firth, Skye, Mull and Lismore using a helicopter mounted-thermal imager. The east coast of England, Firth of Tay and the Moray Firth were surveyed using NERC's fixed-wing aircraft. Based on the results of these, and earlier surveys, the minimum size of the British common seal population is estimated to be 25,936. Britain holds nearly 40% of the population of the European sub-species *Phoca vitulina vitulina* and about 5% of the world population of the species.

The current status of most common seal populations in Britain is unclear. Counts made on the east coast of England between late July and early August showed an average increase of 3.5% per annum between 1969 and 1988. The population in this region was reduced by about 50% following the 1988 phocid distemper epizootic. **Populations in Scotland which were surveyed before the epizootic and in 1989 were apparently little affected. It is not possible to estimate the effect of the epizootic on the total British population, but it was much less than elsewhere in Europe, where many common seal populations were reduced in size by up to 60%. Many of these have begun to recover, and some have almost reached their pre-1988 levels. Although there is some evidence from Britain, the Netherlands and Denmark that a distemper virus is still circulating in the North Sea, no mortalities amongst wild seals which are directly attributable to the virus have been reported.**

The Conservation of Seals Order (England) (No.2) 1990 provides year round protection for common and grey seals on the east coast of England and was introduced to promote the recovery of the common seal population there. Counts of common seals in the Wash in 1989, 1990 and 1991 were virtually identical. Although the results of the 1992 survey are 5% higher than the equivalent 1991 figures, it is not clear that this represents the beginning of a recovery. SMRU recommends that the Order should be renewed until there is evidence of a statistically significant increase in common seal numbers on the east coast of England.

Surveys of Shetland carried out by SMRU in August 1991 provided no evidence of an increase in the common seal population since 1984. NERC therefore recommended that year-round protection of Shetland seals should continue, and the Scottish Office introduced the Conservation of Seals (Common Seals)(Shetland Islands Area) Order 1991. In early January 1993, the tanker MV BRAER was wrecked on the southern tip of Mainland in Shetland, releasing over 80,000 tonnes of light crude oil into the sea. The immediate effects on seals appeared to be slight: none of the seal deaths recorded at the time of the incident could be attributed to the effects of oil, although seals in the immediate vicinity of the wreck did show evidence of the chronic effects of hydrocarbon vapour inhalation. However, the full impact of the EXXON VALDEZ oil spill on the common seal population of Alaska was not evident for a number of years and it is too early to assess the impact of the BRAER spill on the seals of southwest Shetland.

The Table below shows the numbers of common seals counted around Britain between 1988 and 1992. For areas which have been surveyed more than once, the most recent counts have been used. As noted above, these data represent the minimum number of seals in each area surveyed.

Population	Date of Survey	Number counted	Survey Method	Status
N & W coast Scotland & Inner Hebrides	1988-1992	8044	Helicopter	Unknown
Dumfries & Galloway	1992	8	Helicopter	Unknown
Outer Hebrides	1992	2278	Helicopter	Unknown
Shetland	1991	4784	Helicopter	Unknown
Orkney	1989	7137	Helicopter[1]	Unknown
East coast Scotland	1992	1850	Fixed-wing aircraft	Unknown
East coast England	1992	1835	Fixed-wing aircraft	Increasing until 1988
GRAND TOTAL		25,936		Unknown

[1] visual survey conducted jointly by SMRU and University of Aberdeen (all other helicopter surveys have used a thermal imager)

The Department of the Environment Northern Ireland and the National Trust (Strangford Lough Wildlife Scheme) jointly count common seals in Strangford Lough, which holds most of the Northern Ireland population. As the Table below shows, counts made in August since 1988 have declined steadily. Pups of the year are included in the total count and are also given in parentheses.

COMMON SEALS IN STRANGFORD LOUGH, NORTHERN IRELAND

		YEAR				
SITE	DATE	1988	1989	1990	1991	1992
Strangford Lough	1-7 Aug	447 (68)	315 (50)	359 (60)	300 (52)	267 (46)
Strangford Narrows	1-7 Aug	665 (102)	469 (75)	537 (99)	418 (83)	336 (57)
TOTAL		1112	784	898	718	603

THE STATUS OF BRITISH COMMON SEAL POPULATIONS

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1. BASIC BIOLOGY

Common seals (*Phoca vitulina*) are considerably smaller than grey seals; adults may be up to 1.8m and weigh 80-150kg. They are more often associated with sheltered coastal sites, including estuaries, than are grey seals. Pups are born in June and early July on rocky islets or inter-tidal sandbanks. They weigh about 10kg at birth and grow to 20kg over a 6 week period. **Although common seals are gregarious and habitually use specific haul-out sites, they do not breed in colonies. Females tend to leave, or move to the edges of, groups and give birth to their pups in the inter-tidal zone. Newborn pups must swim with their mothers at the next high tide.** Moult occurs between mid-June **and early September, with young animals and** females moulting earlier than males. During the moult individuals, especially males, haul-out more consistently and for longer periods than at any other time of year.

2. NORTH ATLANTIC POPULATION

The common seal has a circumpolar distribution with four well-recognized sub-species. In the North Atlantic *P.v.vitulina* is found as far north as Svalbard and as far west as Iceland (Figure 1); *P.v.concolor* is found on the north-east coast of the USA and throughout eastern Canada as far north as Baffin Island. Following the large scale mortality of European seals caused by phocid distemper virus in 1988, Britain now holds nearly 40% of the world's population of *P.v.vitulina*. It holds about 5% of the world population of the species.

3. SURVEY TECHNIQUES

Until 1984, SMRU estimated the abundance of common seals by counting the number of animals hauled-out in particular regions from boats, in July at the end of the pupping season. It was believed that such counts gave some indication of the productivity and minimum size of the local population. However, it is now known that the haul-out behaviour of common seals at this time is not consistent and that some pups have already dispersed widely by mid-July and are unlikely to be counted. Thus estimates from such surveys are not sufficiently precise or accurate to provide a useful indication of the status of British common seal populations.

Throughout Europe, surveys of common seals are now carried out between late July and mid-August, when most animals are moulting and the largest number of seals are usually recorded. Repeat counts of the same areas at this time of year give consistent results. Published estimates of the relationship between the number of seals counted in late July and August and total population size are available for only two European populations. Telemetry studies in Orkney (Thompson and Harwood 1990) have indicated that males spend almost all their time hauled-out at this time of year while individual females spent 59% of their time hauled-out (95% confidence limits 42-75%). This result suggests that total population size in Orkney may be 23-59% higher than the peak count obtained from surveys in late July and August. Härkönen and Heide-Jørgensen (1990) estimated that total population size for common seals in the Kattegat/Skagerrak was 30% higher than the count obtained from aerial surveys, based on the number of seals found dead during the 1988 phocid distemper epizootic and the mortality rate estimated from aerial surveys in 1987 and 1989.

On the east coast of England and Scotland, common seal haul-out sites are on sandbanks. These are easily located and seals can be counted from vertical aerial photographs. Elsewhere in Scotland, most haul-out sites are on seaweed covered rocks; haul-outs are difficult to locate and seals cannot be counted easily. Fortunately, groups of seals on rocks can be readily detected using a thermal imaging camera; this device is now used by SMRU for all surveys in this kind of terrain.

3.1 Thermal image surveys 1988-1992

These surveys are carried out using a thermal imaging camera mounted in a helicopter, a technique which allows a large section of coastline to be surveyed quickly and efficiently. Surveys are carried out within two hours of low tide because studies of haul-out behaviour have shown that numbers decline considerably outwith this period. All grey seals which are hauled-out are also recorded on these surveys.

During a survey, thermal images are recorded onto video tape. The size and location (within a 100m square) of each group of seals are marked on 1:50,000 Ordnance Survey maps together with the date and time of the record. This information is entered into a computer database at the end of each survey flight.

The entire north and west coasts of Scotland (from Duncansby Head in Caithness to the Cumbrian border, including the south shore of the Solway Firth as far as Silloth), plus all islands in Shetland, Orkney, and the Outer and Inner Hebrides, have been surveyed between August 1988 and August 1992. In 1989, large sections of the coast which had been surveyed in 1988 were resurveyed to assess the effects of the phocid distemper epizootic. Certain sections of coastline (Mull, Lismore, and the Ascrib Islands and Loch Dunvegan in Skye) have been surveyed every year since 1988. In response to changes in numbers of seals in north-west Skye over the past four surveys, the whole of Skye was resurveyed in 1992. Sections of the east coast of Scotland (from Duncansby Head to Golspie, Findhorn Bay to Carnoustie and the coast south from St. Andrews) and outlying islands (St. Kilda, the Flannans, Sule Skerry, Sula Sgeir, North Rona, Sule Stack and Fair Isle) have not been surveyed. In the latter case, this was due to CAA restrictions on the use of the survey helicopter over open water.

The distribution and numbers of common seals in Scotland during early August are shown in Figure 2. Circles represent the total number of seals observed in each 10km square, centred on the midpoint of that square. Where there are replicate counts (Mull, Skye, Lismore, and the west coast from Kyle of Lochalsh to Moidart), the mean of these has been used. A total of 24,101 common seals and 10,110 grey seals have been counted. Table 1 shows the numbers of seals in areas which have been surveyed repeatedly. In general, there appears to be only limited variation in the number of seals counted from day to day and from year to year within a particular locality. Figure 3 shows the distribution of common seals on Skye in 1988, 1989 and 1992. Circles represent the number of seals counted in 1km squares. The decline in numbers of seals in north-west Skye appears to be due to redistribution because the total size of the local population has not changed since 1988 (Table 2).

In August 1991, Shetland was surveyed using a thermal imager to assess seal populations in order to review the Conservation of Seals (Scotland) Order 1973b. The survey provided no evidence that the common seal population had increased since 1984, and the Conservation of Seals (Common Seals)(Shetland Islands Area) Order 1991 was introduced in response to NERC's recommendation. This Order continues to provide year-round protection for Shetland common seals.

Orkney, which was visually surveyed by helicopter in August 1989, will be surveyed using a thermal imager in August 1993. After this survey, the whole of Scotland, with the exception of the relatively seal-free parts of the east and north-east coasts, will have been surveyed using thermal imagery. The feasibility of surveying the entire coastline in two or three years, rather than the current five years, is being investigated.

3.2 Aerial surveys of the east coast

Surveys of the common seal population in the Wash (England) using NERC's fixed-wing aircraft were carried out regularly by SMRU between 1969 and 1982. They were discontinued in 1983 following the death of the survey team in a helicopter accident. Surveys of the Wash recommenced in 1988 and were extended to include the north Norfolk coast, the Humber estuary, the Firth of Tay (since 1990), and the Moray Firth (since 1992).

Counts made in the Wash between late July and early August show an average increase of 3.5% per annum between 1969 and 1988 (Figure 4). The population in the Wash and the surrounding area was reduced by about 50% following the 1988 phocid distemper epizootic. Counts in 1989, 1990 and 1991 were all around 1,500 individuals. The 1992 count of 1,632 (Figure 4, Table 2) was about 5% higher than previous counts. The average number of seals counted per 10km square on the east coast of England, between the Humber estuary and Blakeney Point, since 1989 is shown in Figure 5.

In the Firth of Tay, 773 common seals and 1,226 grey seals were counted in August 1992, with 1,077 common and 250 grey seals in the Moray Firth (Figure 2). In one haul-out group in the Moray Firth, the species identity of 166 seals could not be determined.

4. EFFECTS OF PHOCID DISTEMPER VIRUS (PDV)

The common seal population in the Wash was seriously depleted as a result of the 1988 epizootic. However, other British populations were apparently little affected, even though relatively large numbers of dead seals were found in the Firth of Clyde and large numbers of dead seals were reported from Orkney. Mortality was undetectable in sections of the Scottish west coast which were surveyed immediately before the PDV outbreak and in the year following. It is not possible to estimate the overall mortality in Britain, because surveys in other areas had not been carried out for a number of years prior to 1988. Elsewhere in Europe, many common seal populations were reduced in size by up to 60%. Some of these increased substantially from 1990 to 1992 (ICES, 1992). Heide-Jørgensen *et al.* (1992) predict that the population in Denmark and Sweden will recover to its pre-epizootic level by 1995-96 because of the skewed age and sex ratio created by the epizootic.

Simple epidemiological models (Grenfell *et al.*, 1992) suggest that PDV should have disappeared from North Sea seal populations by 1990. **However, up to 50% of grey and common seals born since 1988 which have been examined in the UK, The Netherlands and Sweden had signficant levels of actively-acquired (ie non-maternal) antibodies to morbillivirus (ICES 1993). This, together with the fact that there was a small scale mortality attributed to PDV in a Dutch seal rescue and breeding centre in 1990 (Visser *et al.*, in press) implies that the virus is still circulating in North Sea seal populations.** Seals from elsewhere in the North Atlantic and Arctic Ocean are also known to carry the virus (Henderson *et al.*, 1992; Markussen & Have, 1992). Thus there is a risk of a recurrent epizootic which could be initiated from within the North Sea populations or by an influx of infective individuals from outside the North Sea. This risk, and the magnitude of the effect of an epizootic, will increase with time as the proportion of unexposed individuals in the North Sea populations rises.

5. EFFECTS OF THE 1993 SHETLAND OIL SPILL

On 5th January 1993, the tanker MV BRAER ran aground on the rocks of Garths Ness on the south tip of Mainland, Shetland, releasing 80,000 tonnes of light crude oil into the sea. Exceptionally severe and prolonged gales smashed the wreck and prevented salvage operations. Oil spread around the south and south-west coasts of Mainland but was dispersed throughout the water column very rapidly. The initial impact on seals appeared to be slight: 22 dead grey seals were either seen or recovered. All of these seals were considered to have died either before the spill or from unconnected reasons. Three common seals and 30 grey seals were taken into the seal rescue centre at Hillswick. One common seal and two greys died while in care, the rest were released.

Initial studies of harbour (common) seals in Prince William Sound, Alaska, the site of 1989 the EXXON VALDEZ oil spill, showed similar results: few oil-affected seals were recovered immediately after the spill. However, by 1992 populations of harbour seals in oiled areas were 35% lower than in 1988, with populations in unoiled areas 18% lower (Frost and Lowry 1992).

6. EXPLOITATION AND DELIBERATE KILLING

Common seal pups were exploited in considerable numbers in the Wash and Shetland until the passing of the Conservation of Seals Act, 1970. Hunting in Shetland was halted by the Conservation of Seals (Scotland) Order, 1973b when it was demonstrated that hunting was removing a very high proportion of the annual pup production. Hunting continued in the Wash until 1973, in Orkney and the east coast of Scotland until 1977, and on the west coast of Scotland until 1981. Since these times licences have been issued only for protection of fisheries. The numbers of common seals taken under licence between 1970 and 1992 (no licences were issued in 1989 or 1990) are shown in Table 3.

An unknown number of common seals are killed legitimately each year by fishermen and the owners of marine fish farms. Figures provided to SOAFD by the Scottish Salmon Growers' Association indicate that at least 215 common seals were killed by its members during 1989 and 1990. In addition, members of the Shetland Salmon Farmers' Association reported that they shot 68 seals (species unknown) in 1989. Most of these were probably common seals because no licence holders in Shetland reported killing any grey seals between 1985 and 1988.

5. REFERENCES

Frost, K. & L F Lowry 1993. Draft final report: Assessment of injury to harbour seals in Prince William Sound, Alaska and adjacent areas following the EXXON VALDEZ oil spill.

Grenfell, B T, M E Lonergan & J Harwood 1992. Quantitative investigations of the epidemiology of phocine distemper virus (PDV) in European common seals populations. *Sci. tot. Envir.* **115**: 145-162.

Härkönen, T & M-P Heide-Jørgensen, 1990. Short-term effects of the massdying of Harbour seals in the Kattegat-Skagerrak area during 1988. *Z. Säugetierkunde.* 55: 233-238.

Heide-Jørgensen, M-P, T Härkönen & P Åberg (1992) Long-term effects of epizootic in harbor seals. *Ambio* 21:511-516.

Henderson, G, A Trudgett, C Lyons, & K Ronald 1992. Demonstration of antibodies in archival sera from Canadian seals reactive with a European isolate of phocine distemper virus. *Sci. tot. Envir.* 115:93-98.

ICES 1992. Report of the ICES Study Group on seals and small cetaceans in Northern European seas. ICES C.M. 1992/N:4.

ICES 1993. Report of the Workshop onthe Distribution and Sources of Pathogens in Marine Mammals.

Markussen, N H, & P Have 1992. Phocine distemper virus infection in harp seals (*Phoca groenlandica*). *Mar. Mamm. Sci.* **8**: 19-26.

Thompson, P M, & J Harwood 1990. Methods for estimating the population size of common seals, *Phoca vitulina. J. appl. Ecol.* 27: 924-938.

Visser, I K G, E J Vedder, H W Vos, M W G van de Bildt & A D M E Osterhaus (in press) Continued presence of phocine distemper virus in the Dutch Wadden Sea. *Vet. Rec.*

6. FIGURE CAPTIONS

Figure 1.	Distribution of the common seal in the North Atlantic.
Figure 2.	Distribution of common seals around the coast of Scotland as revealed by aerial surveys carried out in August between 1988 and 1992. The size of each circle is proportional to the number of seals counted in a 10km square
Figure 3.	Numbers and distribution of common seals in Skye in August. Circles are centred on the mid-point of 1km squares.
Figure 4.	Results of aerial surveys for common seals in the Wash carried out between 1968 and 1992.
Figure 5.	Distribution of common seals on the east coast of England. The size of each circle is proportional to the number of seals counted in a 10km square.

NUMBERS OF COMMON SEALS IN AREAS SURVEYED MORE THAN ONCE USING A THERMAL IMAGER

		YEAR				
SITE	**DATE**	**1988**	**1989**	**1990**	**1991**	**1992**
Applecross	7 Aug	48	26			
Plockton	6-7 Aug	282	158			
Skye (total)	4-6 Aug	1233	1269			1296
Skye (part) Loch Dunvegan + Ascrib Is.	4-8 Aug	549	598	395	342	366
Kyle	4-7 Aug	43	15			
Sleat	7-8 Aug	43	53			
Loch Nevis	7-8 Aug	30	68			
Arisaig	7-8 Aug	456	499			
Mull	2-3 Aug	607				
Mull	8-9 Aug		940	1008	883	825
Lismore	2-3 Aug	535		491		
Lismore	7-8 Aug		369	425	405	340
Lismore	10 Aug		398			

TABLE 1. Numbers of common seals counted in areas of the west coast of Scotland which have been surveyed more than once between 1988 and 1992.

NUMBERS OF COMMON SEALS IN AREAS SURVEYED MORE THAN ONCE USING A FIXED-WING AIRCRAFT						
		YEAR				
SITE	DATE	1988	1989	1990	1991	1992
Firth of Tay	7-13 August			467	670	773
Donna Nook, Lincolnshire	1-16 August	173	126	57	0	18 0
The Wash	1-16 August	3035	1580	1532	1551	1645 1618
Blakeney Point	1-16 August	701	307	73	0	84 217

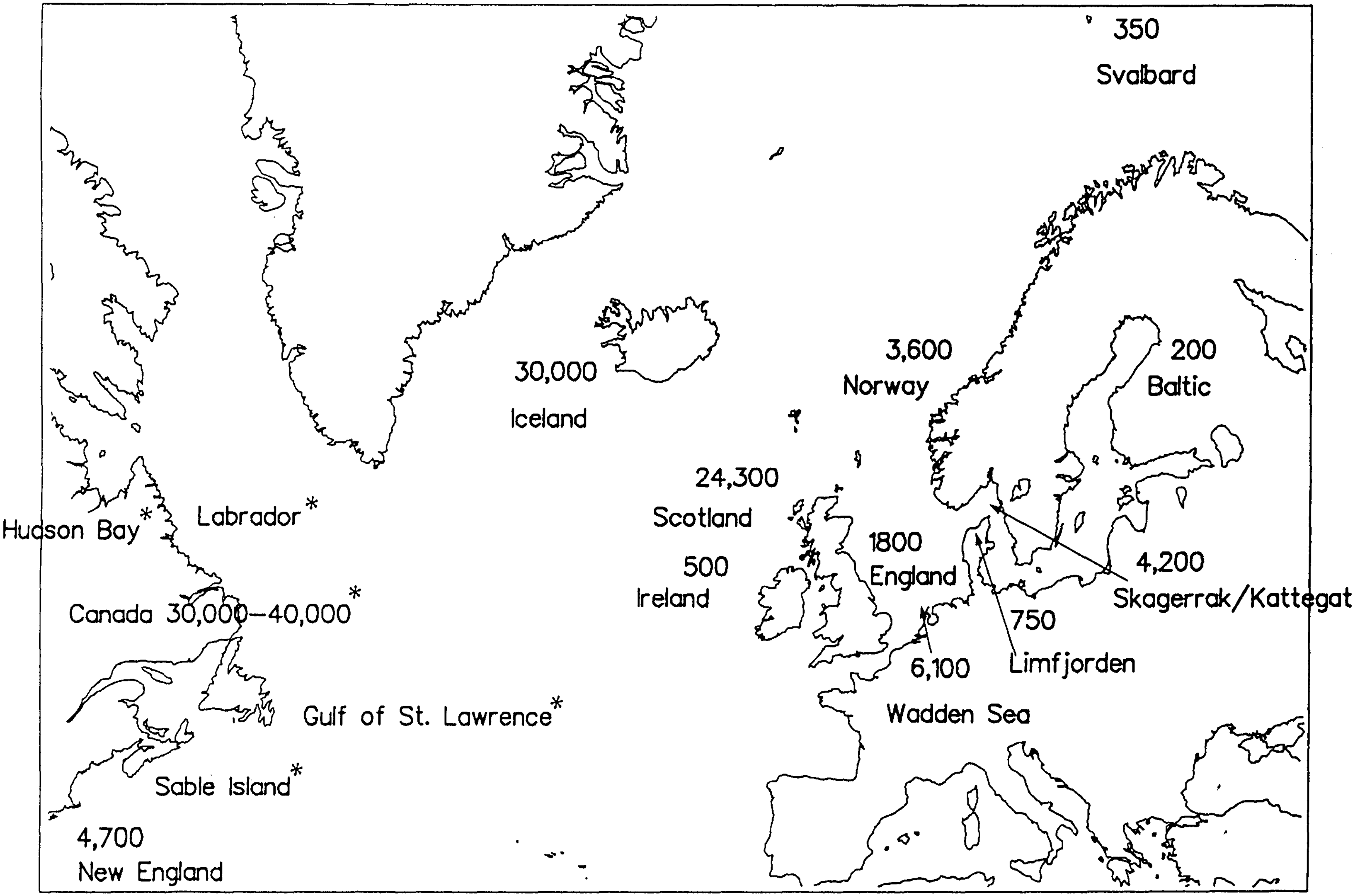
TABLE 2. Numbers of common seals at sites on the east coast of Britain which have been surveyed more than once between 1988 and 1992. The absence of seals at both Donna Nook and Blakeney Point in 1991 was probably due to disturbance by visitors.

Year	Outer Hebs	W. coast Scotland	E. coast Scotland	Orkney	Wash	Shetland
1971		250 + 17 ad	58 + 8 ad	12	303 + 12 ad	
1972		200 + 30 ad	61 + 9 ad	116	380 + 5 ad	
1973		250	59	198	382 + 13 ad	
1974	15	235	87 + 18 ad	198	1 adult	
1975	50	190	50	86	1 adult	
1976	42	208	104 + 17 ad	96		
1977	39	211	34 + 6 ad	17		
1978		340	-	-		
1979		350	-	-		
1980		350	5	28		
1981		350	3 adults*	-		
1982		3 adults	-	2		
1983		-	-	-		
1984		-	-	-		4 ad*
1985		1 adult*	-	-		3 ad*
1986		22 adults*	-	-		10 ad*
1987		-	-	-		12 ad*
1988		44 adults*	30 adults*	-		23 ad*
1989		-	-	-		
1990		-	-	-		
1991		-	5 adults*	-		
1992			1 adult			

* Taken around salmon nets or at fish farms.

TABLE 3. Numbers of common seals killed under licence in Great Britain since 1971, including those taken under scientific permit. All figures refer to pups unless otherwise indicated.

Figure 1



Distribution and Abundance of Common Seals in the North Atlantic

Fiqure 2 Common seals in August 1988 - 1992

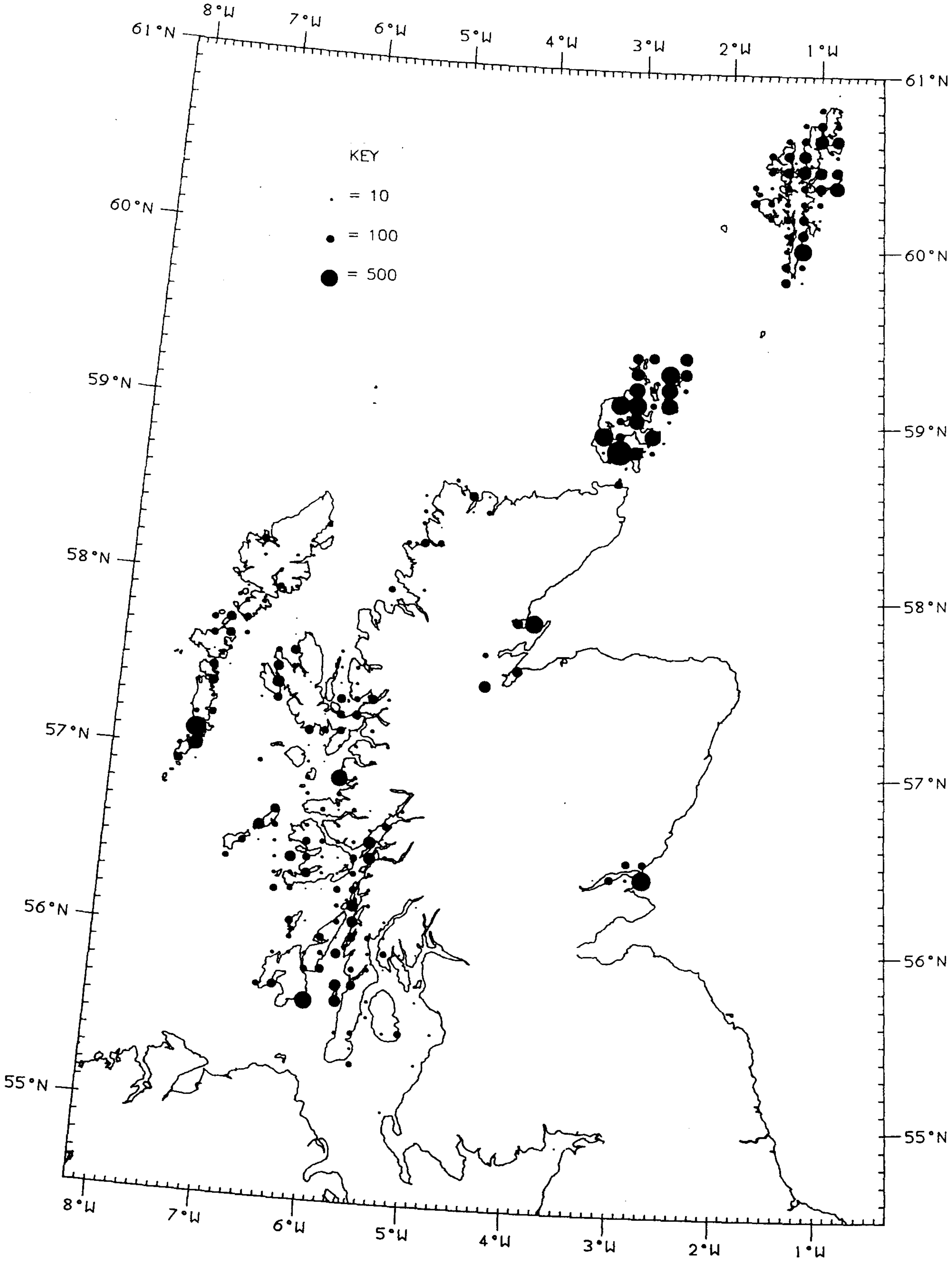
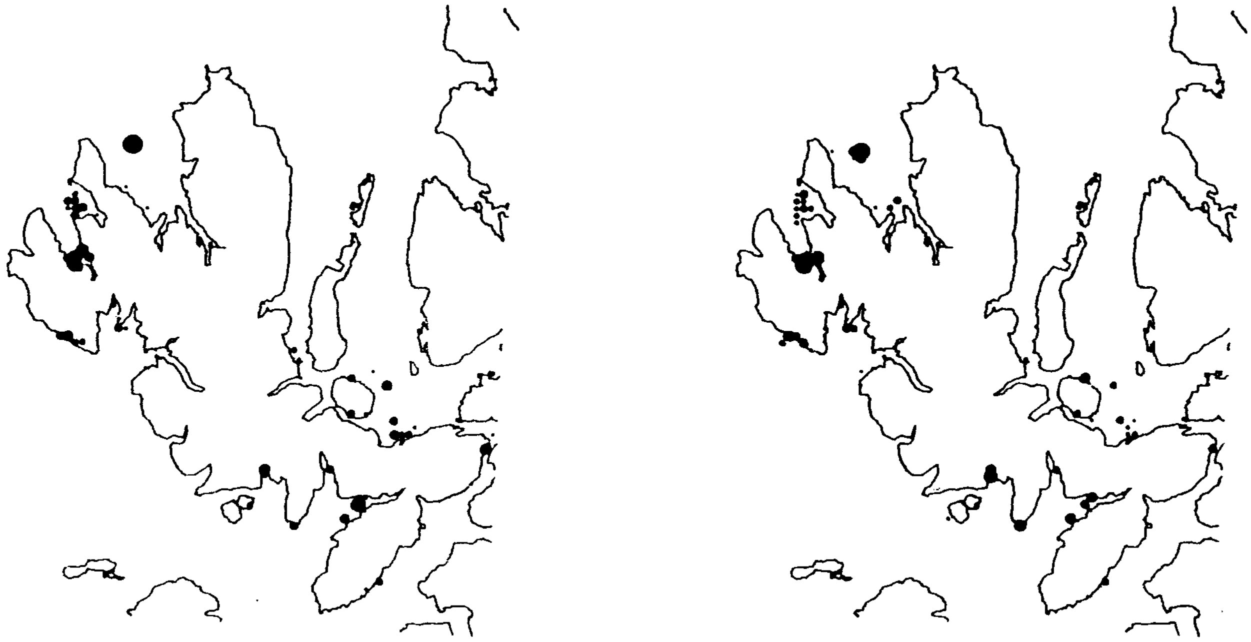


Figure 3



1988

1989

1992

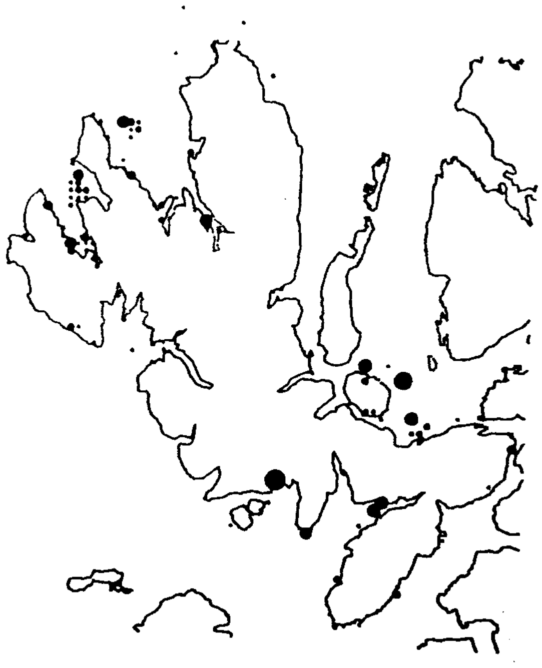


Figure 4

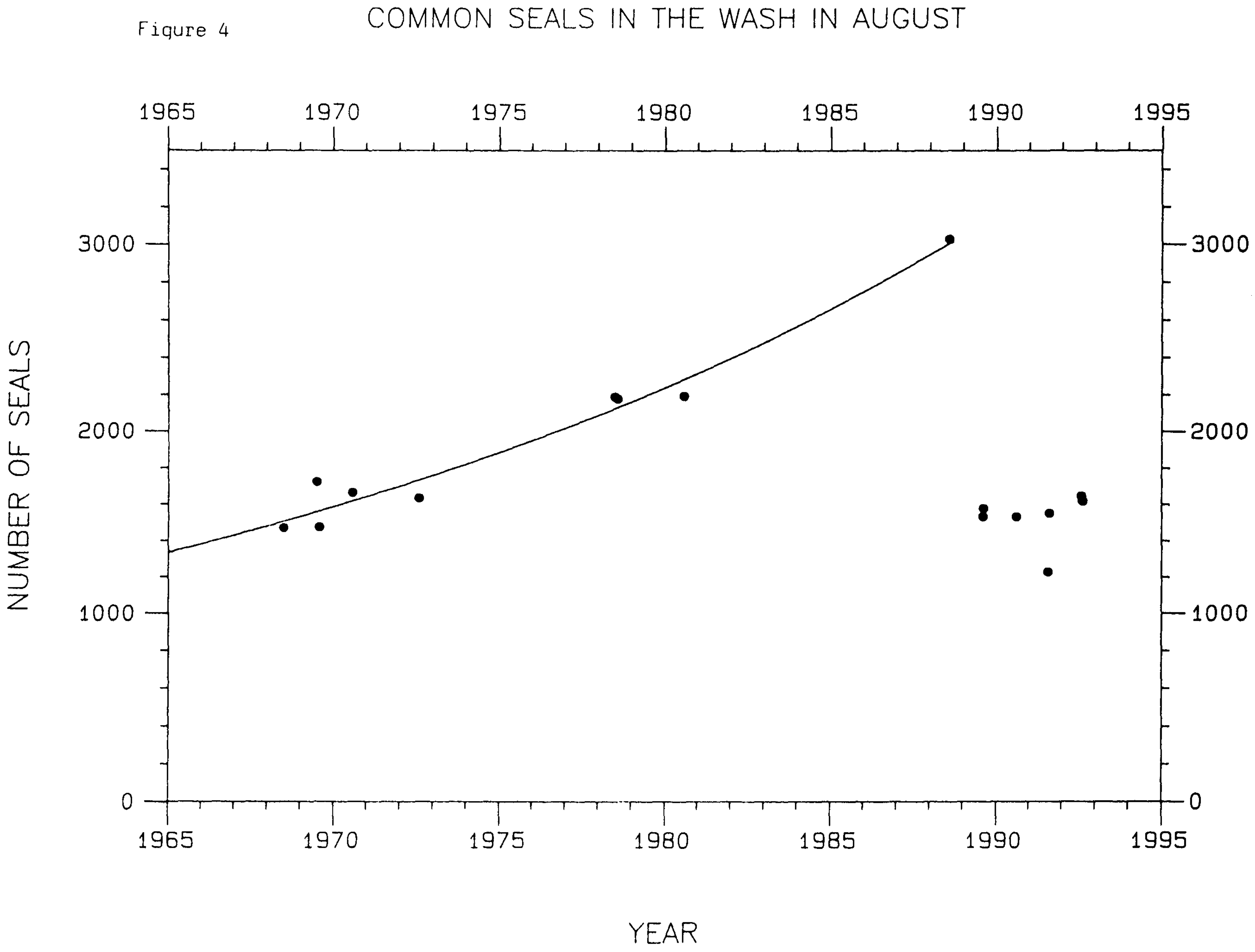

COMMON SEALS IN THE WASH IN AUGUST
1965
1970
1975
1980
1985
1990
1995
NUMBER OF SEALS
0
1000
2000
3000
YEAR

Figure 5 Wash common seals - August 1989-1992